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ABSTRACT

Presented is a compilation of eight articles relating to science teaching in England, primarily at the secondary school level. An editorial describes recent changes in sciences and science education, decreased student enrollment in science courses, and increasing emphases on scientific methods training. The articles are then presented in three categories: chemistry, physics, and physical science and education. The headings are: Chemistry for the Beginner: A Plea for Sound Chemical Education; The Sixth Form and Chemistry; Educational Theory and Neoteric Practices in Physical Science Teaching; The New Laboratory--Its Apparatus and Servicing; SI (System International) and Its Possible Effects on the Teaching of Physics in Secondary Schools; Physical Science for Girls; "Can a Study of Science Educate?"; Science in a Comprehensive School; The Schools Council Integrated Science Project; and Technological Studies in School. Curriculum development is the major concern of the last three articles. The Nuffield scheme is the focus of discussion in most articles. Included is a directory of scientific equipment manufacturers, a bibliography on recent ideas about physical science teaching, and two examples of work sheets used in comprehensive schools. (CC)

ASPECTS OF EDUCATION · TWELVE

A New Look at the Teaching of Physical Sciences

45p

ASPECTS OF EDUCATION

A New Look at the Teaching of Physical Sciences

Guest Editor W. H. Laughton

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GUEST EDITORIAL

THE teaching of science has a long history, and the more one delves into this the more one is inclined to agree with the writer of Ecclesiastes who said that there is no new thing under the sun.

This statement, however, must be qualified because it is quite obvious too that the world has changed so much that it would be almost incredible to a Rip Van Winkle who had been blacked-out for no more than a couple of centuries.

Most of these changes have come about as a result of the application of science so that mechanical appliances have removed much of the need for physical effort, electronic devices have taken over the work of many of the routine activities of the brain and electro-magnetic developments during recent years have eliminated the necessity for physical contact or assembly to achieve communication. These are fantastic changes and all the result of the accelerated advance of technology.

It would seem clear that it is changes of this nature that have been largely responsible for the neoteric approaches to the teaching of science; for instance photographic techniques in the teaching of physics and semi-micro methods in the study of chemistry owe their introduction to the technical progress achieved in photography and glass technology respectively. This is not to imply that such changes are unnecessary or even unimportant. The introduction of the direct reading balance into the chemistry laboratory has meant a saving of both space and time with consequent gain to the study of the subject. Similarly television technical developments have made it possible for the oscilloscope to become a piece of school physics equipment almost as common as an ammeter.

Happily in the course of all this dazzling change there are recognisable invariants, or at least features which are changing so slowly that there arises no communication or credibility gap between one generation and another.

There is the body of knowledge which has its base in the schools and its growing points in the post-graduate studies of the universities. Whilst from time to time there are arguments as to what fraction of the body of knowledge of a subject can be introduced at school level, there is a broad consensus of opinion on the fundamentals. One only has to compare a neoteric series of text books, e.g. Nuffield, with a standard set having a traditional approach to realise that in both one is dealing with virtually the same topics and to a similar depth. The difference is mainly one of approach.

This current approach, for all its newness, would be a recognisable technique to the pioneers of heurism and would even have been applauded by Francis Bacon and the founders of the Royal Society. They were learned men who recognised the value of both experience and experiment in the study of nature.

This urge to pupil participation in creative learning was first taken up in the infant and then in the junior school. It has received strong support from the Piagetian school of psychology and it has been successful in the sense that it has made the learning process enjoyable and what has been learned has been understood at the child's own level.

In some places these learning techniques have been given the title of 'pupil research', thereby implying that in this process the child is discovering something for himself and largely by himself. It is a pity that the words 'discovering' and 'research' have been brought in to describe these popular and effective methods of pupil involvement in learning. The child is continuously 'discovering' from birth as his perceptions widen, deepen and are refined. He does not unearth facts which until his 'discovery' of them had not been generally recognised. Occasionally he invents; that is to say he devises new techniques for achieving his ends. This is part of the synthetic process that Piaget reminds us precedes the achievement of analytical ability. It is this juvenile lack of analytical powers that makes the use of the term 'research' most inappropriate. Any competent research involves the worker in a painstaking and often tedious analysis of the field in which he is interested. Only when that has been done and a plan of attack on the problem devised is there opportunity for the play of insight and creative thought. Even then only half the work has been done and the researcher is faced with more analysis as he tests hypotheses and falsifies where he can. This is an adult activity and is not to be confused with the freshness and ingenuity of the questing young mind.

The secondary stage of schooling has traditionally been the place where the development of a scientific attitude of mind was supposed to arise incidentally to a study of one or more of the sciences. School science experiments besides illustrating natural processes provide material for exercises in deduction and hypothesis formation and testing.

The best known champion of this use of school science material was, of course, H. E. Armstrong, whose views dominated a generation or more of school science teaching. The ebbing of this tide coincided with the opening of the area of atomic and nuclear physics pioneered by Ernest Rutherford in the early years of this century. It then became clear that the scope of school science would have to be extended to include some of these newly discovered phenomena.

This raised the problem of time. Either more periods in the week had to be found for science or else the syllabuses would have to be pruned considerably. More time was not easy to find with new subjects like economics and sociology coming over the school horizon and it was equally difficult to decide what in the basic knowledge leading to the study of a science could be left out. The trend was to keep separate the theoretical and practical with the former carrying the pupil along at a pace far outstripping the development of the latter. The theoretical tended to become increasingly mathematical—especially in physics—whilst the practical developed a technique of its own which was related to little else outside the school. This was particularly true of practical work in chemistry with the emphasis in qualitative and volumetric analysis. It was rather like the traditional type of work in arithmetic and algebra in which a solution had to be found by the application of one or more standard techniques.

By the end of the fifties the multiplication of new topics in both physics and chemistry made it increasingly necessary, particularly at 'A' level, to decide what to leave out of the school covering of the subject. In physics heat lost ground, sound gained a little but in a new guise as part of an integrated study of wave motion.

Geometrical optics was revolutionised by the invention of the raybox and the curriculum was frequently unified under the inclusive concept of energy. The detailed work on mirrors which took up so much time in the study of optics was made unnecessary by the emphasis placed on reflection in the empirical study of transformation geometry.

Two other changes were taking place which in different ways affected the schools' attitude to the teaching of science. One was the swing away from interest in the sciences, which for a number of years now has left unfilled vacancies in the science places at universities and has led to many universities having to accept candidates of a standard lower than they would desire and considerably lower than that of students entering faculties other than those of science.

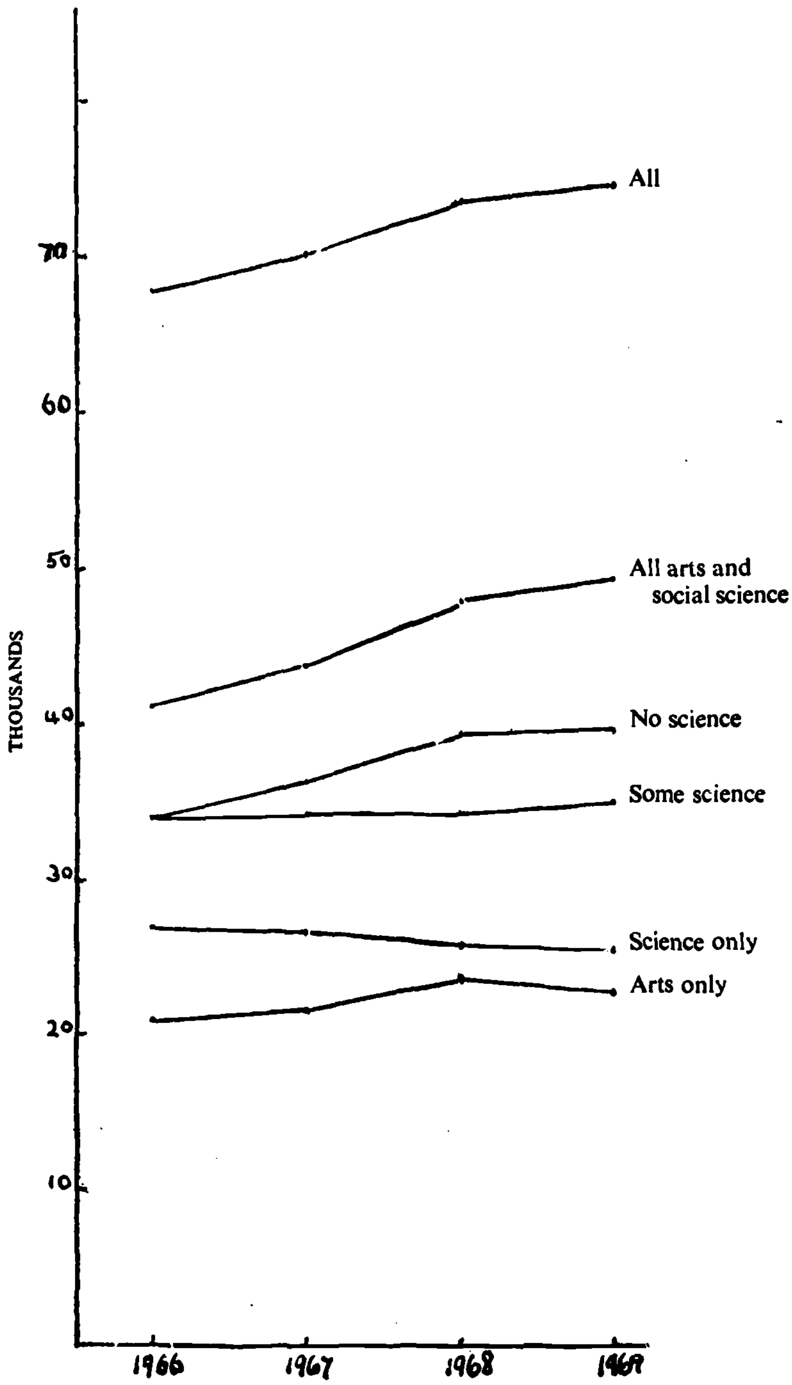
The accompanying table and graph based on material from the most recently published figures illustrate the difficult situation which science faculties continue to face. Whilst this swing can be partly explained by the increasing popularity in school sixth forms of social science courses, there seems to be other factors which have not yet been satisfactorily revealed.

Percentage of leavers with two or more 'A' level passes obtaining place at university

Year	Science only			Arts only			Arts and or social studies		
	H	L	All	H	L	All	H	L	All
1966	90	47	65	81	19	42	72	16	36
1967	90	53	70	76	15	40	72	12	33
1968	90	57	71	71	16	39	74	12	34
1969	90	54	71	78	14	39	73	11	32

H—Passes with two subjects at C grade, or better.
L—All other passes.

The other notable change affecting the teaching of the sciences has been a widespread move towards comprehensive schools and mixed ability teaching. With this there has been in science a decreasing emphasis on content and more on the discipline of scientific methods. The necessary organisational modifications have involved both teachers and pupils in more



Pupils with two or more 'A' level passes 1966–69 inclusive.

responsibility and harder work. The lecture demonstration has had to give place to worksheet and individual assignment, with the result that on average any one pair of a class of thirty can expect to receive less than seven per cent of a teacher's time. Under such organisation the academic excellence of the more intelligent and interested is bound to depend increasingly on personal motivation. It is too early to say whether this new emphasis on method at the expense of subject matter will bear desirable fruit. On the one hand there are those who argue cogently that one who is trained in the use of the complementary processes of induction and deduction and in the appreciation of the statistical validity of results will be of more use in general world affairs than one who 'knows' a certain but limited amount of knowledge in a science. On the other hand universities and many other institutions of further as well as higher education are demanding recognised standards of achievement on which to base their specialist courses of study in the many fields of engineering as well as in both the applied and pure sciences. The dilemma remains.

The challenge presented by the swing away from science was matched by an equally important call for action from industry. In spite of the upgrading of Colleges of Advanced Technology to university status the image of industry in the eyes of the upper school was not improved. Even the higher financial rewards in industry have not been attracting sufficient applicants of high calibre. In 1966/7 4·8 thousand men and women went up to universities to study technology but only 4·5 thousand in the following year. Over this same period arts, pure science and social studies all increased their intakes. There are a few schools like Oundle which, by tradition dating back to the famous F. W. Sanderson, have had close links with industry and a strong element of practical bias in the curriculum. Only recently, however, have the possibilities of this approach been exploited on a large scale. Under the title of Project Technology, pioneering groups in various parts of the country are now enlisting the pupils' urge to invent into the service of science learning. This may be seen as carrying a step further the policy of relying more on the human innate desire and ability to synthesise which has been shown to precede the acquisition of analytical interest and expertise.

In this issue we have looked briefly at the question of education in science for girls, particularly those in the average ability range. It has yet to be shown that both girls and boys can receive maximum benefit from the study of science when no attention is paid to the sex differences of their interests. It is well known that there are good historical and social reasons for the lack of attention that physical science has received in girls' schools, but there appear to be sound psychological reasons for believing that after the initial stages in the middle school years girls would find more interest in a physical science curriculum more closely related to the average woman's eventual preoccupation—home and family. Here perhaps there is room for the emergence of the Home Economics equivalent of Project Technology.

There always has been the problem of what line to adopt with those who, in the sixth form, take up or continue the study of a science as a cultural activity with no idea of making it central to their higher studies. Here there is a strong case for looking at the philosophical aspects, particularly when these can be linked to a study of the history.

Finally the introduction of SI units raises problems which need airing, and we ought to appreciate not only that the change is being made, but the fundamental reasons for this change.

Most of the topics touched on in the above paragraphs have been dealt with usefully and at length by our contributors. They not only feel that the subjects they have severally dealt with need ventilation but they invite discussion which unfortunately cannot take place in this journal. We hope it will be possible elsewhere.

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CHEMISTRY FOR THE BEGINNER: A PLEA FOR SOUND CHEMICAL EDUCATION

J. Bradley

1. Two moments in the work of physical science

The first moment of thrust into the unknown is heuristic discovery, the moment of adventure. It is the glad acceptance of what nature gives, a rich sensuous experience, and a moment in which man finds little scope for his reasoning faculty. It is followed by a second moment, that of explanation, or systematic theory. Here logical conclusions are drawn from theoretical postulates and the conclusions tested by either experiments in the laboratory, or experiences in the larger workshops of land, air and space. Since this kind of theory is not the only kind in science I call it here S-theory, short for systematic theory, or theory of the 'conceptual system' type.

In an interesting conversation (January 1968) Mr. N. Booth, H.M.I. suggested to me that, in their *Sample Scheme*,[1] the authors of the *Nuffield Chemistry Basic Course* have sought to capture both these moments of scientific endeavour, in order that the children may enjoy a properly representative scientific experience even if they do not pursue the study of chemistry at the sixth form level or higher. Thus in the Stage I (A alternative) there is some suggestion of heuristic teaching. For an exercise in this phase of science, the authors have inevitably selected the oxidation of a chemical element. Their treatment could easily be improved, but it proceeds in a way which I think is, at least for a fair number of pages, compatible with sound teaching.[2] On p. 86 of the *Sample Scheme* there is an unfortunate break in the sequence of ideas and materials. Sulphuric acid is dragged in as "a more convenient way of preparing hydrogen in the laboratory".[3] If this work is presented in about the fifth term of the course, as I think it should be, the pupil is greatly helped by a more thorough continuity of material. It is true that pre-Nuffield chemistry teachers sometimes erred in the same way; I protested against this lack of coherence in chemical material as long ago as 1933.[4] A simple way of avoiding the break in this example is shown very briefly here:

(*a*) The oxidation of copper.
(*b*) Nitrogen from air.
(*c*) Extension from copper to mercury.
(*d*) Isolation of oxygen from air of room by Lavoisier's mercury experiment.
(*e*) The name oxygen from sulphurous, carbonic and phosphoric acids.
(*f*) Sulphurous acid turned into sulphuric acid by means of mercuric oxide or in some other way.
(*g*) Hydrogen from cold water and magnesium.
(*h*) Hydrogen from magnesium and sulphurous acid, from magnesium and carbonic acid, and from magnesium and sulphuric acid.
(*i*) Zinc and sulphuric acid.

In my view, *coherence of doctrine* is a more important issue than *heuristic presentation*; nevertheless one welcomes what the Nuffield authors have achieved in the way of heuristic teaching. It is very little indeed, and comes as an anticlimax after the glowing promises of the *Introduction and Guide*.[5] One suspects that the numerous authors and consultants have as it were cancelled each other out; the H.C.F. is commonly smaller than any of the numbers. Any good teacher with thirty years' experience could have produced something much better and more lively than the *Sample Scheme*, provided he was allowed to do the job single-handed.

With respect to the second moment, that of systematic theory, the authors of the Nuffield Scheme make a bold break with traditional chemistry teaching and introduce the periodic classification of the elements early in the third year of the school course.[6] On p. 267 of the *Sample Scheme* the teacher is advised in these terms:

"Point out that below carbon in the Periodic Table is another element, silicon, which we would expect from previous experience to have similar properties to those of carbon".

This certainly does exemplify the moment of verification of an S-theory, although the theme of the carbon/silicon analogy must be unintelligible to the pupil. In my own teaching, I found that the second year of the sixth form is the ideal time to bring in the Table. Attempted earlier, the response is poor because the pupils have too little knowledge of the common elements and compounds. To suggest that the Table can help pupils aged 13, who have no idea how any atomic mass at all can be determined, is surely phantasy.

2. The foundations of chemical knowledge

In addition to the S-theory, a sound knowledge of chemistry requires theory of a more fundamental and profound character. This theory, called for convenience F-theory, is found at its most important in the meaning and use of the terms *element* and *compound*, together with the correlative term *chemical change*. There are many other necessary concepts in F-theory, but none so important. It was Armstrong's belief that children could discover concepts for themselves, not merely facts. Once in my own school career, I was able to vindicate Armstrong. A pupil of mine at Brigg Grammar School called the gas which blackens copper 'good air', and he had carefully studied the formation of the black coat of copper and the blue coat of iron from the metals and part of the air. He also had made 'red coat on mercury' from mercury and air, and 'separated good air by itself' from the red coat. He was then asked to study the action of heat on a mixture of iron and black coat on copper. Here is a report from his note-book which I recorded over thirty years ago:

"The iron filings and black copper coat were pushed firmly down and heated. This was for a purpose so that the two mixed substances could take in nothing from the air. Then it was heated, and the *unadulterated iron filings* of the mixture began *to do its stuff*. If Lavoisier was right the black coat of copper should contain air. Therefore if the iron filings cannot get good air from outside *to do its stuff*, it will take the good air out of the black coat. That must be what happened, because when the good air was taken out of the coat by the filings *pure copper* remained out of the black coat".[7]

This proves that a boy can seek out and find the concepts of *element* and *chemical change*. Compound is defined in the manner of Boyle: where A and B are elements, or other sub-units, then

$$A + B \longrightarrow Z,$$

Z being a new substance quite unlike A and B, and Z is called a *compound*. Processes leading to the removal of compounds, or to the formation of compounds, are *chemical changes*. When the compound is defined like this, the status of the law of constant composition as an empirical generalisation is safeguarded. If, on the other hand, compound is *defined* as that which has a fixed composition, the law of constant composition becomes what philosophers call '*analytical*'. It is better, in teaching chemistry, to retain the *synthetic* status of the law of constant composition. The easiest way to do this is to follow Boyle's classical treatment.

The treatment of this in the *Sample Scheme* is disappointing.[8] In Stage IA, there is a slight and pointless reference to *compound* on p. 35, many pages *earlier* than a brief discussion of *element* on p. 68. At this same stage (Stage IA) the concept of chemical change is hardly used at all. It seems to me that here, the authors of the Nuffield chemistry books are disloyal to their own science. They present chemistry with its specific phenomenon omitted! In their experiments the phenomenon *occurs*, but it is not *noticed* in its peculiar and special particularity. It is as if they had never noticed the miracle of a red crystalline solid which is composed of a silvery liquid metal and a colourless gas or the miracle of the wetness of water. This insensitivity to chemical change itself is astonishing in men who claim to be the improvers of chemical education.

What I have called here the F-theory is a necessary part of the foundation for any sound knowledge of chemistry. Other necessary parts of this foundation are many simple physical and chemical facts. Yet the Nuffield authors have thought fit to omit many of these, and leave the treatment of others to chance. The very important theme of the solution of air in water is an 'option' in the Nuffield Scheme.[9] I would urge that this *possible* omission cannot be justified, particularly when simple chromatographic processes appear as a necessary part of the scheme.[10] I would like to ask the Nuffield authors to reply to this complaint. If I am wrong about this, why am I wrong? It is a simple test case, and there are many others.

The idea of revising the foundations of a science because of recent advances is suspect. The old foundation stones, whether simple facts or F-theory, are still needed. The quantum theory itself requires a Correspondence Principle, whereby it becomes firmly based on the rock of classical physics.

3. Significant phases in the history of chemistry

Chemistry before Boyle (1662) is not very relevant to the student today. The first phase which matters to him is that of F-theory, associated with Boyle, and noticed above.

The second phase is the eighteenth century revolution in science inaugurated by Lavoisier and brought to fruition by Berzelius. These two chemists, aided by many others, classified the elements as metals and non-metals, related these classes to typical oxides, related the oxides to bases and acids, and studied general reactions between metal, non-metal, oxide, base and acid. Inspired by the chemical and electrochemical resemblance between chlorine and oxygen, Berzelius gave to the terms oxidation and reduction meanings which they still carry today. The modern concept of electronegativity is simply a way of stating 'how non-metallic an element is' and is thus a natural consequence of this second phase of chemical history. Lavoisier himself predicted from his own classification of elements, oxides, acids, bases and main reactions, that magnesia and quicklime would turn out to be oxides of metals;[11] there is, therefore, a touch of S-theory about this second phase.

The third phase of chemical history is more plainly S-theory: the chemistry of Dalton, Gay-Lussac, Avogadro, and Cannizzaro. These men restore the atomism of Boyle and of the ancient thinkers. In the process of restoration, the atomism becomes indirectly a theme for experimental investigation at the bench. Cannizzaro showed (1858) that the patient and extended application of Avogadro's hypothesis yields molecular formulae such as

$$CH_4/CH_2Cl_2/CCl_4/COCl_2/H_2O/O_2/COH_2/$$

in which one hydrogen atom seems *to be worth* one chlorine atom, one oxygen atom is *worth* two hydrogen atoms, in which —more briefly—the principle of constant covalency is exhibited. This is the first proof, or *a posteriori* verification, of Avogadro's hypothesis.[12] In the same monograph, he showed that the only way of determining relative atomic masses is through Avogadro's hypothesis. Exceptions to this statement, e.g. the Dulong and Petit specific heat rule, are apparent only.[13]

Mendeléeff's periodic table is the second proof of Avogadro's hypothesis, and constitutes a fourth phase of history. It is a two-dimensional array of atomic masses, every one of which is based on Avogadro's hypothesis. Not only is Mendeléeff's table the main key to modern chemistry; it is also a return to the classificatory second phase. Mendeléeff could no more have done his work without Lavoisier than he could have done it without Dalton.

I am not advocating that chemistry should be taught historically; but I am gravely disquieted by schemes of work which appear to hold the history of chemistry in contempt. In less than 400 words I have sketched four great chapters of chemical history; in the teaching of chemistry these major turns of the fine story should be respected. In really great chemistry teaching, what I have called here the respect for history would be a part of the reverence for life itself. This reverence for life, so finely commended to us by the life and teaching of Albert Schweitzer, spreads downwards from the fear of God through respect for man, animals, sticks and stones. A man's sacramental regard for the common substance water is not likely to be lessened by his chemical insight into that remarkable compound. The teaching of the late Henry Worth at Archbishop Holgate's Grammar School, York, was sacramental in this sense. Many chemists are still alive to bear witness to the strange—properly religious—power of Worth's teaching.

4. The case against the Nuffield Scheme

With regard to the two moments of physical science discussed in the first paragraph, the timing is incorrect. At the beginning of the third year, the first moment has not been vividly felt by the pupil so it is pointless his proceeding to the second. He cannot interpret his experience by the periodic table, for he has so little experience to interpret. The table is as much help to him as logarithms would be to a child of seven faced with the problem 2×3. I have seen a class of children peering at the pretty colours of cobalt carbonate and nickel sulphate, and then copying down that cobalt and nickel are transitional.[14] On inquiry, I found these children did not know the chemical resemblance between cobalt carbonate and chalk, they did not recollect what a carbonate is, and they had never thoroughly examined carbon dioxide. Surely that is a travesty of chemical education. My contention is that *school chemistry up to Ordinary Level should in the main be chemistry of the first moment of science*, although tiny beginnings of S-theory are necessary and useful in appropriate places.

Secondly, in the Nuffield Scheme, there is no attempt to lay a sound foundation in the mind of the child, and this is related to the disrespect for history. Neither F-theory nor the Lavoisier revolution are significantly treated in the *Sample Scheme*. For example, carbon dioxide is introduced quite early in the course[15] merely to be reduced by magnesium, although the important gas has not been prepared from its elements and examined carefully. A little later the pupils "must be told" what is the action of an acid on a carbonate[16] and the study of chalk is reduced to a few lines of advice.[17] Lavoisier's great classification of the elements is presented without its factual basis.[18] The neutralisation of acid by base is hardly noticed, and the example given is esoteric in itself and educationally vitiated by employing the conductiometric technique.[19] The difficult concepts of 'salt' and 'ion' are used freely with little attempt to clarify them, and with little to support them in the pupil's mind. Most damaging of all, in the curiously placed study of hydrogen chloride and chlorine,[20] there is no reference to the great oxygen/chlorine analogy. I predict that the universities will reap the whirlwind from this confusion in a few years' time; I love chemistry too much for this to give me any pleasure.

By courtesy of the editor of *The School Science Review*, I was recently permitted to publish a sound syllabus of the older type.[21] I would like to draw attention to some of the advantages of this syllabus.

(1) The elements hydrogen, oxygen, chlorine and nitrogen are prepared in quantity and examined adequately.

(2) The acidic oxides carbon dioxide, sulphur dioxide, nitrogen dioxide are prepared and examined similarly.

(3) The three important mineral acids are prepared in a variety of ways and examined thoroughly. The examination includes the reduction of the two oxyacids by copper, and this is taken as an extension of the first problem, i.e. the oxidation of a metal such as copper.

(4) The electromotive series of metals is used in an extended way. By its means, and from 'the copper problem' together with nine rough stability rules, almost the entire content of the proposed syllabus is knit into a convincing and easily digested whole.

(5) The goal of the course is the Lavoisier classification of elements with Berzelius's notable additions in the way of eleven

fundamental general reactions. Every time one tests carbon dioxide with lime-water one thinks of the neutralisation of an alkali by an acid to form a salt. The metal is oxidised within the carbonate as it is in other salts. This Lavoisier insight is what the pupil needs.

When the first two phases of chemical history are omitted it is impossible to lay a sound theoretical foundation. Without foundations and ground floor, only jerry building is possible. With regard to the third phase of history, I have been somewhat dissatisfied with what was done in the past,[22] but I can see little advantage in the suggestions of the *Sample Scheme*. Although I do not entirely share the late Mr. George Fowles' view that the loss of equivalent theory is disastrous, it is worth noting that determinations of equivalents do take the student back to the bench. Such exercises have value even if their theoretical meaning is only partially understood. In any event, I feel we are unwise to disregard Mr. Fowles' opinion, the opinion of one of the greatest chemistry teachers of recent years:

"In agreement with other experienced teachers . . . I steadfastly maintain that the equivalent, with its broad sweep of the fundamentals, is an essential component of elementary theory . . . It behoves the Nuffield Chemistry leaders, who have for too long kept their critical judgement in cold storage, to take it out forthwith, and restore the equivalent to its rightful place in the scheme."[23]

One of the most absurd features of the Nuffield scheme is the practical exercise of making a magnesium oxide lattice model from polystyrene balls.[24] Again I would point the question: What in the experience of these young children does this lattice model interpret to their minds? If the answer to this question is: Nothing, then I suggest that the authors should admit the fact, and confess that they are wasting the time of both teachers and children.

Not less absurd is the claim "that the treatment of the Periodic Table at this stage should be historical".[25] The tone of this comment is that history is an easy let-out for the immature and very young student, and that an advanced student would not waste his time with such trivialities. I have already indicated what is the correct historical place of the Table. If the Nuffield authors think that a treatment of the Table *prior to the experimental determination of the atomic masses* can be in any sense historical, they do not know what history is, or they have no respect for it. History is much more than an odd date or two with the addition of a funny story about John Dalton's double pair of socks. Mendeléeff's great work is of course in the fourth phase of the history of chemistry. This phase has no place at Ordinary Level.

Thirdly, the *Nuffield Scheme* is spoiled by a large number of experiments which are much too advanced for the beginner. Most of the work on reaction rates,[26] systems in equilibrium,[27] organic substances[28] in the treatment of which there is a gross philosophical confusion of the *substance* with its *molecule*, plastics,[29] the world food problem,[30] heat of combustion[31], which is a pointless excursion into thermodynamics and can in no sense "speak to their condition", and other topics, fall under this category.

5. Coherence of doctrine

In the attempt to bring chemistry teaching up to date the Nuffield authors have produced a scheme of work which is so strained and ambitious that, like a piece of overstretched cloth, it has torn itself into holes. Little coherent remains. It is an invitation to play with chemistry rather than to master it. It will repel the good minds. Indeed I see it as a part—regretfully not the only one—of the contemporary movement against education itself. It is an anti-intellectual programme and must be fought as such.

Is it honestly a "sample scheme"? Many of us do not care for its taste and wait for the second sample. I offer this example of coherence to the authors of the second one:

(1) The metals sodium, magnesium, zinc, copper and mercury combine with oxygen with decreasing vigour.

(2) In particular, mercury combines with it reversibly and this leads to oxygen.

(3) Copper is not oxidised by either water or dilute acids.

(4) Copper oxide and copper carbonate react with dilute acids, because the oxide and carbonate are already oxidised.

(5) Copper reacts with hot strong sulphuric acid to form a salt for the acid oxidises the copper first.

(6) The preparation and properties of sulphur dioxide, the reduction product of sulphuric acid.

(7) Nitric acid oxidises copper more readily than sulphuric

acid. Nitric acid is less stable than sulphuric acid, and so a stronger oxidising agent.

(8) A comparative study of the two acidic non-metal oxides, sulphur dioxide and nitrogen dioxide.

(9) Although both are reducing agents, one will oxidise the other (Lead Chamber process).

(10) Hydrochloric acid is a reducing agent.

(11) Chlorine is very like oxygen, and hydrochloric acid is very like water.

(12) Neither water nor hydrochloric acid react with copper.

Most of the other two-thirds of a sound Ordinary Level syllabus will crystallise out on this seed.

The poor little fellows who keep us employed come to school asking for bread. Shall we give them a stone?

Dr. J. BRADLEY began his higher studies in science as a Major Scholar at Emmanuel College, Cambridge in 1927. He graduated with honours at both Cambridge and London and followed this by obtaining his Masters' degree for studies in the History and Philosophy of Science, a field which he has since made peculiarly his own. His teaching career began at Wallasey and Christ's Hospital, followed by senior appointments in the teaching of chemistry at Brigg Grammar School and the Crypt School in Gloucester. In 1949 he joined the Department of Education in the University of Hull, where he has not only fashioned the expertise of many teachers of science but also researched into the work of Mach, which resulted in his taking the degree of Doctor of Philosophy in 1966. Dr. Bradley has many published articles to his credit and is widely regarded as a staunch protagonist of a soundly based heuristic approach to the teaching of science, particularly chemistry.

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THE SIXTH FORM AND CHEMISTRY

E. H. Coulson

As a preliminary statement to this article, it must be made clear that most of the ideas and opinions contained in it are personal to the author and do not necessarily represent points of policy held by any organisation with which he is connected.

When discussing the position of any subject in the school curriculum there are a number of factors which must be taken into account. This contribution will be concerned mainly with three such factors, namely, the context in which chemistry is to be taught in the sixth form, the content and approach to possible courses in chemistry, and the examining methods appropriate to the first two factors.

In recent years there has been a very considerable concentration of effort on course content, and on new methods of examination. The context in which such courses are to operate has, however, been a matter of some doubt, especially so far as the sixth form is concerned. A number of proposals designed to increase the breadth of the sixth form curriculum have been made during the past ten years. These have emanated mainly from the combined efforts of Schools Council and the Standing Committee on University Entrance. Most of them have involved subjects being studied at different levels but these have been considered unworkable on closer scrutiny. The latest scheme, devised by the Briault/Butler committees[1] has been made public whilst this article is being written. This recommends that, in general, all sixth form students shall study five subjects for examination purposes in the first year, using five-sevenths of the time-table allocation in this way, and three subjects on a similar time allotment in the second year. The remainder of the available time would be devoted to unexamined studies and other activities. To secure breadth of studies a single nationally agreed grouping scheme is suggested, the form of which will ensure that a student predominantly interested in arts takes at least one science subject (or mathematics), and prevents a science based student from taking more than two science subjects plus mathematics. There are, however, certain 'escape clauses' in the proposals which would permit a third science subject to be started (or continued) in the first year, using part of the time set aside for general studies, and continued into the second year, at the end of which it could be examined.

To meet the examination requirements of the new proposals, the joint committee recommends the setting up of a national committee to oversee two new examinations, the Qualifying Examination at the end of the sixth form first year, and the Further Examination at the end of the second year. It is not clear whether this is in fact a recommendation for a new national examining board but the general tone of the part of the report dealing with examinations gives the impression that this may be so. It may seem a little strange that a scheme designed to remove the pressure of so-called specialist examinations should seek to do this by an increase in the number of available examinations. Since neither 'O'-level examinations nor the C.S.E. are recommended for abolition, it seems plain to anyone who knows anything about schools that the vast majority of the abler pupils will continue to take these examinations at the age of 16, for an insurance against possible future failure if for no other reason; and who shall blame them or their teachers for this state of affairs. Consider then the plight of the type of pupil that the joint committee seeks to help. He develops rather late and is deemed suitable for the C.S.E., in which, somewhat surprisingly, he does rather well. Encouraged to continue, he takes a group of 'O'-levels the following year, and with continuing success, 'Q'-level and 'F'-level examinations. He gets a university place and takes meaningful examinations at the end of his first, second, and third years of tertiary education (if he goes to a technical college or college of education the pattern will not be very different). For seven years he faces an annual examination, with at least a fail/pass situation attaching to each.

As I write this article, within a week of the appearance of the new proposals, there are indications that they are not going to find general acceptance. Individuals known to be receptive to new ideas and forward looking in their outlook on educational affairs are commenting that the new scheme will be quickly forgotten, as have been those that preceded it. Ultimately, any set of proposals in this area of the school curriculum, or in any other such area, must depend for their implementation of the willing assent of teachers, students, and examiners. It would seem desirable, consequently, that the opinions of these three groups should be taken into account from the beginning of an exercise of this kind. In this connection a survey of the composition of the two committees responsible for the joint statement is revealing, and in some measure alarming. Of the eighteen individuals (apart from the secretary) whose names are appended to the statement, five are university professors (none from a department of education), five are administrators, seven are head teachers or principals (also largely administrators in the present educational system), and *one* is a practising teacher (a mathematician). In the light of this analysis the statement that "The nature of the sixth form curriculum and the Qualifying and Further Examinations cannot be left entirely to practising teachers" in the annex to the report will not come as a surprise to anybody. Truly the working parties practise assiduously that which they preach. Perhaps, however, the teachers may count themselves fortunate in comparison with the examining boards and students, whose views were not represented at all.

To be fair, the introduction to the joint statement contains the sentence: "We have examined submissions made to us in writing and have had valuable discussions with representatives of a number of bodies". It will be noted that there is no suggestion that submissions were invited or discussions sought. In fact, the reverse is the case, if the experience of the Association for Science Education is any guide. This Association, of whose affairs I can claim some knowledge, has been active for nearly seventy years. Between them, its 12,000 members can command detailed and expert knowledge of all aspects of science teaching in schools. It was not approached by the SCUE/Schools Council working parties for opinions on the matters that they were discussing. The A.S.E., becoming aware, more or less fortuitously, that discussions in this area were proceeding, submitted evidence on its own initiative but whether or not this was taken into consideration it has no means of ascertaining. If this example is typical, it is not surprising that the proposals betray lack of knowledge of what is going on both in curriculum development and revision of examination techniques at the present time.

There is a growing body of opinion that exercises of the kind undertaken by the SCUE/Schools Council working parties are not particularly relevant to present day needs with regard to what is or should be done in secondary schools. A broad education through a balanced curriculum is not necessarily to be achieved only by means of restricting rules and regulations which are unlikely to command the willing assent of students and teachers. Given stimulating teaching in courses that are seen to be relevant in the social context of the time most of the present difficulties will disappear. Such courses are now becoming available and we would do well to let their effects become apparent rather than inviting confusion and possible chaos by adopting a policy of introducing fundamental reforms at impracticably short intervals of time. The most pressing need for a balanced curriculum is in the first five years of secondary education. It is here that pupils should be exposed to a wide range of subjects so that through experience they can determine which of them they wish to continue in the sixth form.

There are four main areas of experience to which pupils should be exposed in the lower school: the service subjects which are essential for effective communication, mainly English and mathematics; the science subjects which enable us to make sense of our surroundings; languages, which also should be directed mainly to communication and not entangled with precious grammatical niceties; and social studies such as history and geography. Roughly equal time allocation is necessary if these are to be kept in balance and about one-fifth of the available time should be devoted to each area. This would leave a residual seven periods or so for physical education, games, craftwork, etc. Within this framework, which can be sufficiently elastic to cope with the special needs of particular groups of pupils, teachers should be given freedom to use the time devoted to each area in the way best suited to their abilities and those of their pupils. We must leave the ultimate responsibility in this matter to experienced and informed teachers; a policy that will entail much more determined efforts than are apparent at present to attract able men and women to teaching as a career and to create conditions in which they will not be found to leave it prematurely for economically more attractive pursuits. Under these conditions the head of a science department can determine how he will utilise the seven or eight periods per week available to him during each school year, taking into account the expertise of his staff and the needs of the pupils for whom he has to plan.

At the end of a fairly balanced course in the lower and middle school, it seems both appropriate and, indeed, essential that young men and women who have made reasonably firm decisions about their future careers should be allowed to exercise preferences for the subjects that they will study in the sixth form. Past experience shows that a high proportion of young people are willing to make some sort of choice at this stage and expect to be given the opportunity to do so. It is easy enough to devise ways and means of coping with the uncommitted, but a choice has to be made at some time, and, for the majority, there is no evidence that the end of the fifth year is too early for this to be done, on very general lines only. Keeping broad options open for the sake of the few is likely to result in the loss of many able pupils who have their own ideas about what they want to do; they will make for the nearest College of Further Education and take a National Diploma course. The choice at this stage will be between a science based sixth form course, or one based on other disciplines. For the intending scientists two subject combinations can provide all that is required, namely chemistry, physics and mathematics, or biology, physical science and mathematics. Again one fifth of the working week will suffice for each subject, leaving 40% of the available time for 'broadening' studies. If the teaching has been of the right kind previous to this there will be no lack of applicants for courses in other subjects than the specialist ones. Culture, whatever the word means, cannot be imposed by tidy administrative regulations.

During their two years in the sixth form, students must be provided with the right kind of experience on which to base a career choice. There is much more to this than exposing them to academic courses in biology, chemistry, physics and mathematics. For national survival we must attract a significant proportion of the more able students into the technological disciplines, and of the less able into careers as technicians, where the need for recruits is even greater. Students mainly interested in chemistry, for example, cannot decide whether they want to become biochemists or metallurgists until they know something of what biochemists and metallurgists do. Such experience can often be given effectively only during the second year of the sixth form since a reasonable grasp of underlying principles is required before it can become meaningful.

This brings us to the second major alteration in school administration that needs to be considered. A much larger gap should be created between the end of a school career which extends into the sixth form and the beginning of a full time course in higher education. One quite simple and inexpensive way of doing this is to make the school year coincide with the calendar year. Holding school leaving examinations in December would allow a full two year course in sixth forms. At present only five terms are available, which reduces the status of the proposed F-level examination for which two terms' preparation only would be possible. In the nine months gap thus created all problems of entrance to higher education could be settled, with both sides having the maximum amount of relevant information at their disposal. Students wishing to change direction as far as further studies are concerned could be given crash courses to assist in this procedure. For many students the interval could provide an opportunity to experience some of the realities of the world at large, through community service or through some other kind of temporary employment. Those leaving school for permanent posts would have a settling in period before resuming education on a part-time basis.

In a situation such as that outlined above the task of revising teaching programmes for the various subjects in the curriculum can proceed smoothly and effectively. This is an area of progress in which the science subjects are away to a good start already in this country, thanks mainly to the initiative and enterprise of the Association for Science Education.[2] In Scotland the A.S.E. proposals were adapted and put into practice as a result of a combined effort between science teachers and the Scottish Education Department; in the rest of the United Kingdom, generous financial support by the Nuffield Foundation has enabled teams of teachers to prepare detailed teaching programmes. Broadly speaking the two exercises have had very similar results, as far as chemistry is concerned. The Scottish scheme[3] has been in operation since 1962, and has been accepted by all the schools for which the Scottish Department of Education is responsible. The material for teachers and pupils produced by the Nuffield 'O'-level Chemistry Project[4] has been available since 1966. The work of the Nuffield Advanced Chemistry Project is now nearly complete and publication of the resulting material commenced in 1970. A very brief outline of the proposals of the last of these is given below, since it is in this area that the author has personal experience; more detailed information can be obtained elesewhere.[5]

Amongst the aims of the Advanced Chemistry Project is the production of a course that provides enjoyment for both teacher and pupil. Too little attention is devoted to the 'fun factor' in the school curriculum as a whole; it is an aspect of course planning which will be vital if studies in breadth are to be a matter of consent rather than of compulsion. School trials during the production of the final materials for publication have shown that an approach to the subject which encourages understanding rather than memorisation, which seeks to secure co-operation from the students in what is done and how it is done, and which involves frequent reference to the economic, social and ethical implications of the work of the chemist in relation to the community at large, does indeed prove to be both interesting and intellectually exciting to students of a quite wide range of abilities. The course is firmly based on practical work conducted on investigational lines, with emphasis on directed inquiry from which arises the need for guiding and explanatory concepts and principles, but opportunities are provided also for students to plan and carry out investigations for themselves. Chemistry is presented as an integrated subject and the treatment ranges across the traditional sub-divisions of inorganic, organic, physical, and analytical chemistry. The objective is to reach a position in which an appreciation of the idiosyncratic behaviour of specific elements and compounds is combined with an ability to look at material systems 'in the round'. For the former purpose the search for patterns of behaviour helps to make sense of an apparently bewildering variety of properties; here the Periodic Table provides a powerful correlating medium. The relationship between structure and properties also plays an important part. Realisation of the second objective entails a study of the ways in which the changes which material systems undergo, or can be persuaded to undergo, depend for their extent and rate on the possibilities of energy distribution within the system; hence a study of the energy changes which accompany and influence material changes is given prominence in the course. Although the conceptual framework of the course is carefully prescribed, the factual information required to provoke, or to test, speculation leading to general principles is capable of very considerable variation, thus making flexibility of treatment possible.

Technological applications of chemical principles form an integral and essential part of the treatment of the subject. Here again the aim is understanding, in this case of the purpose and methods of technological research and development, of the intellectual challenge of such activities, and of their relevance to society. Much of this understanding will come from second-hand experience, in the shape of specially written case histories, but it is proposed also that students shall spend some time (about four to six weeks in the second year of the course) on a practically based special study of one area of chemical technology, such as metallurgy, chemical engineering, food science. In this part of the course extensive use has been made of advice, and of assistance with written material, from practising technologists.

At the end of a course, especially one that can lead to further study at a higher level, it is traditional to require students to take an examination. In the past insufficient attention has been given to the objectives of external examinations. It has sometimes been assumed, perhaps implicitly, that putting the candidates in some sort of order of merit is enough, but this is unacceptable at the present time. If one proceeds from the assumption that the role of an examination is to provide some means of investigating to what extent the stated objectives of a given teaching programme have been achieved, a more rational approach is possible. Objectives can be defined in terms of intellectual and manual skills and abilities, of course content (both factual and conceptual), and of activities which the successful completion of the course demands. To test all these a flexible and varied system of assessment is needed. This is an area in which much research is required before a wholly satisfactory solution can be found. For the 'A'-level examination at the end of the Nuffield Advanced Chemistry Course, a combination of fixed response questions, structured questions, free response questions and teacher assessment has been used up to the present time. Use of the first two types of question permits detailed specification of papers to be prepared so that a predetermined weighting is given to each of the main course objectives. Free response questions encourage and reward facility in communication, breadth of study, ability to synthesise and marshal an argument, and use of the imagination in a controlled but creative way. Teacher assessment is used for allotting marks for practical work. There is a need to provide for teachers to become more specifically involved in these examinations and it is envisaged that they will play an increasingly important part as experience accumulates.

Both the new chemistry courses and the examinations following them encourage a very considerable breadth of study, not a little of it in areas hitherto considered outside the scope of the subject, and also provide opportunities for interlinking with other disciplines of widely differing kinds. It is suggested here that much of real educational value will emerge by concentrating our limited resources of finance and manpower on exploiting the progress made recently in the teaching of chemistry and the other science disciplines, on encouraging similar progress in other subjects, and on establishing a curriculum in the lower and middle school that is balanced with respect to the needs of the last half of the twentieth century. It seems both foolhardy and dangerous to try to solve the educational problems of the future by attacking that part of the schools system in which we have been most successful in the past, to the envy of many other countries—our sixth forms.

E. H. COULSON was head of the science department at Braintree County High School for nearly 20 years before accepting an invitation to join the Nuffield Science Treaching Project in 1962. He is now organiser of the Advanced Chemistry Project, which published its proposals for sixth form chemistry in 1970. Mr. Coulson was chairman of the Science Masters' Association in 1953, vice-president of the Royal Institute of Chemistry from 1962 to 1964, and chairman of the Association for Science Education in 1969. He has been a chief examiner for chemistry at both Ordinary and Advanced level.

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PHYSICS

EDUCATIONAL THEORY AND NEOTERIC PRACTICES IN PHYSICAL SCIENCE TEACHING

W. J. Wilkinson

Introduction

The title of this article includes the term 'neoteric' rather than such terms as new, modern or Nuffield for two reasons:

1. One cannot readily use the terms modern or new science without introducing some confusion as to what is implied. It may refer to modern research developments as is usually meant by the phrase 'modern physics' or, with reference to modern developments in science teaching, it may refer to those most recently introduced.

2. It is somewhat inaccurate, if not rather limiting, to use such a term as 'Nuffield' to indicate modern trends, as 'Nuffield' science is just one possible scheme which certain teachers have developed in the hope that improved methods of teaching will become more widespread in schools. To some teachers it has become an emotive term in that they think of 'Nuffield' science as distinct from other sciences instead of regarding it as one possible way of fulfilling definite objectives in science training. There is no doubt that these schemes will be modified, in the light of future educational developments and other neoteric approaches.

The aim in the following discussion is to indicate how recent developments in educational theory relate to changes in physical science teaching. The organisers of recent trends have undertaken their programmes of improvement with the object of ensuring that pupils, after the assimilation of the new material, will derive greater and more permanent benefit both in the classroom and in later life. Two aspects worth noting in new approaches to science teaching are (*a*) greater class activity in which pupils are left more to discover relationships for themselves and (*b*) with the widespread introduction of comprehensive education, the greater use of worksheets (see article by Yates and Underwood). The important question to be asked is whether or not pupils are capable of benefiting more from the use of such methods and, if so, are there certain conditions which must hold, before they can do this.

Scientific thinking

Training in scientific thinking or problem solving assumes that a large number of attitude and behavioural changes will occur in pupils (Obourn, 1956). They include the following to mention only a few; looking for the natural cause of things that happen, basing opinions and conclusions on adequate evidence, formulating significant problems, analysing problems using appropriate experimental procedures and organising the data obtained. Now these are all major aspects of teaching science which require pupils to reason in a very formal and precise manner. What then are the factors which govern whether or not a pupil is capable of attaining to this level of mature thinking? The most important of these, namely: maturation, changes in attitude, level of experience and appropriate teaching methods are discussed here.

Maturation

Piaget (see Beard 1969) developed the theory that an individual passed through several well-defined stages of intellectual development according to his age—sensori-motor (birth–two years), pre-conceptual thought (two–four years) intuitive thought (four–seven years), concrete operations (7–11 years) and formal operations (11–15 years). It is only at the latter stage that pupils can achieve full scientific thinking. All is not as simple, however, as the above stages would imply.

Piaget and Inhelder (1958) in one of their experiments showed pupils how a pendulum was constructed and made to oscillate. The pupils' task was to determine what governed frequency. Their behaviour fell into four categories. Those children five or six years of age were unable to approach the problem objectively as they could not dissociate their own actions from the effects. They pushed the bob firmly to get greater frequency without considering the role of weight or length. Children aged seven discovered that shortening the length of the string increased the frequency but did not succeed in eliminating all the remaining variables. They were not able to set up an experiment to prove the adequacy of their hypothesis. If they believed that the frequency change was due to both weight and length of string they would vary both at once. Even at 11 and 12 children were usually unable *spontaneously* to devise unambiguous experiments. With guidance, however, some success could be achieved. This is where guided discovery comes in. It was only when he was 13 or 14 that the adolescent would spontaneously devise an experiment in which he would vary only one factor at a time while holding the others constant. Lovell (1969) believes that the above experiment carries the implication for teaching "that the pupil cannot be expected to compass problems which require hypothetico-deductive reasoning unless he has previously had the opportunities to carry out in turn all the organisations upon which such reasoning is founded".

Inhelder (1958) and Lovell (1961) carried out experiments in flotation with a whole series of objects including a toy duck, a toy boat, a large block of wood, stones, a nail, a piece of wax, a metal can, etc. Pupils aged 11 or 12 expressed some notion that an object floated because it was lighter than an equivalent volume of water. It was not until considerably later (13 or 14 in the case of Inhelder's subjects and 15 in Lovell's study) that the concept could be verified using a hollow cube. In order to understand the idea of flotation the pupil has to construct the notion of 'an equivalent volume of water'.

The distinction between different concepts and thus their relative difficulty for pupils to understand, e.g. density and specific gravity, was clearly pointed out by Lunzer (1969). The concept of density is an intuitive one while specific gravity, being the relationship between displacement and mass, is the product of formal reasoning.

Another study showing the difficulty pupils have with scientific thinking is that of Mealings (1961, 1963) who investigated how pupils interpreted simple experiments in physics and chemistry. He established with great regularity pupils' weaknesses in setting up hypotheses, testing them and systematically eliminating the untenable even for pupils aged between 13 and 15 years. Pupils had to be 17 or more before these tasks were correctly accomplished.

One problem investigated was a white powder consisting of a mixture of salt and chalk. The 57 pupils did the experiment individually and all their actions and conclusions were noted. They were given dissolving, filtering and evaporating equipment together with water and hydrochloric acid. As they were to find out if the mixture was one or two substances the experiment involved two hypotheses—a one-salt or two-salt substance. Over half the pupils, although they reported observations correctly, gave no evidence that their actions were directed to the above hypotheses. Their procedure was mainly trial and error although their average age was 14+. Only three pupils were able to reach the correct solution involving the elimination of the one-salt hypotheses. These three had mental ages of 18+. However, nine pupils with average mental age of 17+ did separate the salts by shaking with water, filtering and evaporating but failed to eliminate the one-salt possibility by using hydrochloric acid.

The implications of such maturation studies on how pupils think and reason in scientific experiments are obvious. For many pupils problem solving at the hypothetico-deductive level is a difficult process. Science teachers, therefore, should not be too optimistic about the ability of many of their pupils to carry out 'discovery' experiments on their own without sufficient guidance and direction, since the spontaneous elimination of alternatives is not obtained until late adolescence. Also it would appear that, for the majority of pupils, science teaching must build on concrete ideas for, at least, the first three years of a secondary school course.

Changes in attitudes

As observed in the discussion on scientific thinking, pupils are required to develop appropriate attitudes. The learning process is dependent on such attitude changes. Why does a person's attitude change and how may this change be achieved? One theory which led to much research is the dissonance theory proposed by Festinger (1957). It is based on the principle of cognitive consistency. Attitudes may have to change if some inconsistency has to be eliminated. Seemingly the human mind has a strong need for consistency. Thus if a person makes statements or engages in activities which are contrary to an attitude he possesses, he will experience dissonance. In order to reduce this dissonance, if no other means of altering his behaviour is available, he will change his attitude.

It is found that attitude changes can be brought about through the influences of someone in authority who has control over rewards and punishments. In one experiment (Smith 1961) it was shown that if the leader was formal, cool and official in asking a group to carry out a task, which was opposed to their existing attitude, then greater changes occurred than if the leader was friendly, warm and permissive. The formal relationship towards the group created greater dissonance and therefore greater inconsistency. This resulted in the greater change in attitude.

There is, however, the recent reinforcement or incentive theory (Janis and Gilmore 1965, Rosenberg, 1965) which contradicts the dissonance one. Those who support this theory argue that the greater the incentives for counter-attitudinal role playing, the greater will be the resultant attitude change. Janis and Gilmore stated their argument in this way. "According to this 'incentive' theory, when a person accepts the task of improvising arguments in favour of a point of view at variance with his own personal convictions he becomes temporarily motivated to think up all the good positive arguments he can and at the same time suppresses thoughts about the negative arguments which are supposedly irrelevant to the assigned task".

An experiment to put these two theories to the test was carried out by Carlsmith, Collins and Helmreich (1966) in which each one of half of the experimental subjects (male high school pupils) was enticed to tell another (a female accomplice of the experimenter) that the experimental task was interesting, exciting, and enjoyable (when, in fact, it was dull). The other half of the experimental subjects wrote an anonymous essay to the same effect. All the subjects were randomly paid either 0·50, 1·50 or 5 dollars. The data from the orally communicating group agreed with Festinger's results assuming the dissonance theory, i.e. small amounts of money were most effective in convincing the subjects that the task was really fun and exciting. Data from the essay writing group indicates just the opposite. Large amounts of money produced the most attitude change in agreement with the incentive theory.

This is an interesting result which indicates how attitude changes in pupils may come about. Writing an essay in the above experiment involved a cognitive task in which pupils brought out positive arguments for an attitude change. Scientific thinking also being a cognitive task, pupils, as a result of carrying out experiments in the appropriate manner, can see advantages in or reasons for adopting necessary changes in behaviour. The carrying out of the experimental task itself should therefore help pupils to become committed to a change of attitude. A rewarding environment should enhance this effect.

To see, therefore, if neoteric approaches to science teaching led to an increase in favourable attitudes, Laughton and Wilkinson (1968) carried out a preliminary investigation on 233 pupils in the first three years of a grammar school course. In all cases the mean scores on their attitude test for the Nuffield group was higher than the mean scores for the non-Nuffield pupils. They also found that the younger pupils who had completed only a year or so of grammar school science showed more favourable attitudes than those who had done two or more years. This held true for both Nuffield and non-Nuffield pupils and would suggest that pupils' attitudes to the study of science gradually deteriorate as the first flush of enthusiasm wears off. This study, however, did not cover the age groups in which more mature scientific thinking is developed.

Experience

From the discussion on maturation it follows that teaching on new topics should be based on concrete experiences. Is it possible for pupils to learn effectively if they are given experiences in advance of their intellectual development? Some studies, for example, on problems of conservation have looked at this question. Wohlwill and Lowe (1962), Smedslund (1961) and Beilin and Franklin (1962) have used various training programmes lasting a few weeks. These all proved to be ineffectual in developing systematic thought unless the child was mature enough. Hunt (1961) put forward the argument that the brain can accommodate modifications in its central processes only when the child meets circumstances which match the schemata already assimilated. It is only then that he is motivated and can cope with the new situation. The pupil cannot assimilate new objects or events until they have meaning for him. Past experiences must be such that they prepare him for the assimilation of new material. From this argument cognitive development is a gradual process building on old material. Studies such as McArthur, Irving and Brimble (1964) led to the conclusion that formal reasoning rarely develops spontaneously in a primitive cultural background and, as we have seen above, only with difficulty in advanced cultural environments.

Thus in physical science teaching we need both to structure our courses effectively to ensure that new material is assimilated and in our methods of teaching to give some guidance and direction so that formal reasoning is acquired.

Methods of science teaching

To be effective, neoteric approaches to science teaching must consider the pupil's intellectual maturity and experience. Learning progresses only if the pupils, through suitably structured material, can find the relevant relations between the facts and the questions posed. They must find these relations *for themselves*, if necessary, with guidance from the teacher. This structuring of material is seen clearly in recent worksheet approaches to the teaching of science to mixed-ability classes. (Kamm 1969).

Recent science courses have stressed the advantages of teaching for understanding rather than on mere rote learning. Some studies give support to this emphasis. Katona (1940) showed that material committed to memory with understanding was retained better than material learned without it. He found that understanding enabled the learner to proceed readily to new learning whereas rote memorisation limited the range of problem solving. He also found that pupils learning with understanding organised their task as best they could and it was only when such organisation did not occur that they regressed to rote learning. Learning with understanding, however, also requires pupils to revise and review previous steps taken in the solution of a problem. Hilgard (1953) found that although pupils learning with understanding were superior on new tasks to those using memorisation, errors were quite common in the former learning process. For example one third of those who learned through understanding made errors in even simple transfer tasks and as many as three-quarters on the most difficult task.

Progressive methods in education advocate greater activity on the pupil's part through various modes of 'discovery'. This in direct contrast to the 'rule and example' techniques which characterise much of traditional teaching. The advantages of these progressive methods over traditional approaches are still not clear. Lovell (1963) found no difference in reading attainments or comprehension with third and fourth year junior school pupils from 'formal' schools as compared with those from 'informal' schools. Gardner (1966) also found no significant differences in cognitive skills between children from experimental and those from traditional-type schools although she found a significant difference in attitudes at the two types of school. Also Pringle and McKenzie (1965) found little reduction in rigidity of thinking with these progressive methods. One study, Gagné and Brown (1961) using learning programmes, does show the superiority of the 'discovery' method over a 'rule and example' method in the acquisition of new concepts. They found that guided discovery was superior to discovery alone. This agrees with what is generally advocated in neoteric science courses. Piaget (1964) puts it this way. ". . . I fear that we may fall into the illusion that being submitted to an experience (a demonstration) is sufficient for a subject to disengage the structure involved. But more than this is required. The subject must be alive, must transform things and find the structure of his own actions on the objects." Self-discovery, Piaget maintains, is the essen f any method of teaching.

Piaget, however, does not leave it there. He has a further important aspect to add to his thinking on method. "When I say 'active' I mean it in two senses. One is acting on material things. But the other means doing things in social collaboration in a group effort. This leads to a critical frame of mind where children must communicate with each other. This is an essential factor in intellectual development." In other words he is advocating that self-discovery methods should take place among groups of pupils so that, by adequate social communication, greater efficiency of problem solving can be achieved. It is only through sufficient verbalisation of abstract concepts, possibly in terms of concrete situations, that clear understanding will be achieved. This means that opportunities for group discussions, especially at sixth-form level, where reasoning becomes more abstract, should be provided in science courses.

Evidence on the success of such discussions methods applied to scientific thinking arises from Abercrombie's study (1960). She found from observations and experiments that first year university students, having just completed their school course, were well grounded in the facts of biology, physics and chemistry but had difficulty in using their information in solving problems which were slightly unfamiliar. They preferred to look up a text-book rather than use their slides or other experimental evidence. Free discussions in small groups on their observations, definitions, evaluation of evidence or views on causation were introduced to overcome the deficiencies. As a result of such discussions, the students became more aware of their individual views or unconscious assumptions. When the students who had taken part in these discussions were compared with those who had studied the normal course of lectures and demonstrations, they were found to be superior in a number of aspects of scientific thinking. They more readily discriminated between facts and conclusions, drew fewer false inferences, considered more than one solution and in their approach to a problem were less adversely influenced by the one preceding it. The results indicated that scientific thinking was enhanced by adopting a more objective and flexible behaviour pattern than the more traditional methods. Success is thus more likely to occur as a result of greater opportunity to verbalise concepts and the adoption of a more critical approach in the presence of peers. With such active group participation, improved attitudes to scientific thinking may be expected.

This leads one to criticise the sole use of worksheets as an efficient method of promoting the best scientific approach. With pupils working individually or in pairs there is little opportunity for group discussions to clarify ideas especially if pupils are all working on different topics. It should be noticed, however, that not all schools which use this method restrict their teaching to worksheets alone. Kamm (1969), for example, writes that "When necessary time is allotted to discussion of topics recently completed, demonstrations, very occasionally theory lessons with a minimum of note taking, written tests and verbal quizzes".

Constructive discussion also leads to a desirable atmosphere. This is clearly shown by the classical experiment of Lewin, Lippett and White (1939). A democratic atmosphere was to be preferred to the authoritarian or *laissez-faire*. This and other advantages of greater pupil activity in science courses have been discussed by Wilkinson (1965).

Summary

Recent researches have been discussed to support the importance of maturation, attitude formation, experience and teaching methods in development of scientific thinking in pupils. The main conclusions are that neoteric courses in physical science, in their development of discovery methods, in structuring courses to conform to pupils' experience and level of maturity, in emphasising understanding rather than rote learning and in providing pupils, especially in the first three years of a secondary course, with plenty of concrete material to build more abstract concepts have conformed to much of the research findings in many psychological studies. Further development of project and group work will lead to greater understanding of physical concepts and thus facilitate scientific thinking. These activities, in allowing pupils to *fulfil* the role of scientists in which they become immersed in their tasks will develop attitudes in the desired direction.

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PHYSICS

THE NEW LABORATORY — ITS APPARATUS AND SERVICING

J. R. Stewart

EQUIPPING a physics laboratory in 1970 is an expensive undertaking. Taking a recently issued price list of one of our more comprehensive suppliers of physics apparatus, the total cost of Nuffield physics apparatus, from items 1 to 180, and allowing the quantities specified for a class of 32 pupils, amounts to over £4,000. It is strange that a head of department may be entrusted with the allocation of this sort of sum through the normal school suppliers, and yet be denied the hard cash to buy a dozen wood screws from the local Woolworth's. The example is perhaps not particularly apt, since there are more economic ways of purchasing screws than in dozen lots at Woolworth's; at the same time there are few science departments, if they are alive and on top of their job, where this situation does not arise once or twice a year, it being impossible to forecast in advance all the needs of a department which is continually experimenting to improve its experiments, its demonstrations. Another incongruity, in times when all should be concerned to get maximum value for money, is the spectacle, still far too prevalent, of teachers searching the catalogues to spend what remains of their annual allocation of money on equipment which they don't really need, because if not spent by a certain date it lapses and is lost forever. Both situations are examples of immaturity of outlook on the part of those financing the schools.

Unfortunately too from the economic viewpoint there are influences, mainly political, which operate against the most efficient methods of stocking a department with apparatus and then using that apparatus to the full. Thus if comprehensive education is to mean anything, it should not mean teaching in classes of unstreamed ability, where the progress of the individual child may be as vicariously determined as it was by the eleven plus examination, the only difference being that in the former, chance will play a continuing part shaping the child's future as compared with the sudden death of the promotion examination. If comprehensive education is to have value, it must surely mean the education of each child in accordance with his ability *in each subject*, with equal opportunities for the child to pursue his particular bent whether it be in the field of handcrafts, music, art, classics, science, sport, languages. The implications of this for the physics teacher about to equip his laboratories are far-reaching. If a child is to find his own level of ability in each subject of his curriculum, in classes of graded ability, there must be an opportunity of transfer between grades, not merely at the end of the academic year when his progress may be assessed largely by his performance in English, if the headmaster is a classics man, or in mathematics if the head is a mathematician; not merely at the end of each term, but more or less continually throughout the session. Thus the physics head of department can expect to have, in the early years of secondary education, perhaps for the first three, certainly for the first two, a full range of ability in his laboratories at the same time, studying the same part of the syllabus. This suggests a minimum of three classes, the good, the average, and the poor ability sections, and many educationists might want to see this increased to four, to reduce the ability range within any given class. Though they may all enter the syllabus on an equal footing at the start of the school session, it would be contrary to the principle of comprehensive education as I have stated it above, if one were to maintain them artificially at the same rate of progress. It follows therefore that when a child's talents, or lack of them have been discovered, it should be possible to promote or demote him more or less immediately.

The second point determining the type of equipment which the physicist will want to have in his school is the inevitably accelerating progress of change. We may have little concept of what education is going to be like in 1990, but one thing is certain, it will be as different from the present day's as today's is different from that of 1950. Already there are signs that the present barriers between subjects in the school curriculum are being broken down. In Scotland, in the third and fourth years of 'non-certificate' courses we are experimenting with the study of topics which involve simultaneous use of a number of subjects. This same involvement characterises some of the work on environmental studies in the primary schools. Experimental schools are being designed where the pupil unit is 120–150, with a corresponding group of teachers. This is only one avenue of possible future development.

The scientist buying capital equipment has to recognise that in a few years his syllabus may have changed beyond recognition, perhaps not in its content but in its method of presentation. As an example, for 20, maybe even 30 years, the standard method of determining Boyle's Law was by means of a J-tube filled with mercury, or with a similar sliding tube apparatus. The measurements taken, and their subsequent manipulation, although they contributed nothing to Boyle's Law, were held to be valuable in themselves as an example of logical deduction. If they obscured the law itself, which in any case was treated as nothing more than an empirical discovery, and as a peg on which to hang the hats of innumerable problems, this was hard luck. Now we tend to ask 'Why?' rather than 'What?', so that the law ceases to be an end in itself, and becomes a step in the understanding of the kinetic theory. With this change of emphasis, we simplify our apparatus. We pressurise the air directly using a bicycle pump, and we read the pressure directly on a gauge, which may for some children be a black box, although we attempt to explain its action. The same change in emphasis has resulted in the development of ticker timers for dynamics experiments, and in the eclipse of the Fletcher's trolley.

Secondly, the teacher must recognise that this process of change applies not only to his syllabus, but with even greater force in the industrial field where his apparatus is made. When Scotland introduced its alternative physics syllabus in 1962, a syllabus which in many respects is similar to Nuffield physics, some schools which adopted it were given what was virtually a blank cheque to obtain what capital equipment they required, the only proviso being that they spent it there and then. Some equipment therefore, needed only in year IV or year V of the course, lay unused in the school for this length of time and moreover, was obsolete when it came to be used for the first time, having been superseded by better and cheaper alternatives in the intervening period. An example of this is the Advance Electronics signal generator type SG65 costing when it first appeared £20, and replacing a £45 Jl type from the same firm.

Planned obsolescence in our equipment may be a desirable thing. One H.M.I., overstating the case, nevertheless put this aspect succinctly when he observed: "If it works, it's obsolete." The best example of this, of course, are our school buildings themselves. Taking on average about five years to build, from drawing board to final occupation, they may well be obsolete before they are used. To parody the Red Queen's remarks to Alice: "We have to run as fast as we can to avoid slipping too far backward!" If we accept that our equipment will have a finite life, either through intrinsic obsolescence or through changes in the syllabus, then we must plan to make as full use of it as possible. The custom-built apparatus, used for one experiment only, must either disappear or be reduced in importance. We have already taken big strides in this direction. The microscope, once the sole property of the biology department, is now being used by chemists and physicists alike to view growing crystals and Brownian motion in smoke cells. Some teachers are irresponsible and unscrupulous enough to use this fact to twist the arm of their supplying authority into providing separate instruments in each department, when instead they should be co-operating to select a microscope which will serve the needs of all. Misguided chemists, and those who seek to keep up with the Joneses in physics, will order Avo 8 multimeters in pupil quantity for conductimetric titrations. More advisers in science are needed, and more power needs to be given to those already in office, to prevent this type of abuse.

Meters are in fact a good example of the advantages of planned obsolescence. If we examine the requirements for Nuffield physics, we find that five ranges of meter are called for, *viz.* 5, 10 and 20V, 1 and 5A. The basic 2–0–10mA meter movement costs £4·25—the price at January, 1970, from Unilab—and shunts and multipliers are 90p each. Five of these and the movement therefore costs £8·75, and if the physics department feel they need twenty of these, the total cost is £175. The alternative, keeping in mind the requirement of planned obsolescence, is to buy twenty each of single range meters, 100 meters in all, of Japanese manufacture which are advertised for example in *Wireless World*. The nearest in physical size to the example I have quoted above is the bakelite panel meter, type MR65, costing £1·75 each, total cost £175. So costs are equal and the Japanese meter has the disadvantage that it must be mounted, presumably by a technician, and 4 mm sockets fitted, all of which costs money. But buying meters in quantities of 100 or more qualifies for a sizeable discount, in fact 25% in this case, while over 200 meters will get 33% discount. This more than covers the cost of the extra materials, and a goodly proportion of the technician's time as well.

Nor is this the only reason for choosing the cheap single range meter. Consider what happens if a movement should be damaged. With Japanese meters you have lost 1% of your entire stock, on one range only, which you can replace for £1·75. With the Nuffield type movement you are down to 95% efficiency and this on every possible range. To replace the movement costs nearly three times as much, so it is sent for repair and the department continues to function at 95% efficiency, possibly for weeks until the instrument is returned. Differences between the two systems become even more marked if two or more meter movements are out of action.

Consider also the situation where an experiment requires more than one meter, e.g. an ammeter and a voltmeter simultaneously. With the shunt/multiplier system the number of experiments is necessarily cut by half, whereas with single range meters there need be no reduction. From the point of view of wear and tear the cheap single range meter also has the advantage. If its performance or accuracy becomes suspect, due to a bent pointer, sticky movement or for any other reason, the teacher is more inclined to throw it in the bucket and replace it than he will with an expensive movement which represents a much greater proportion of his stock, and he is loath to send it for repair if it can still be made to work by judiciously tapping it. So old and decrepit meters continue to permeate physics departments to the point where it would be an illuminating experience for the sixth former to connect all the movements in series, pass a suitable current through them and then calculate the standard deviation of the resulting readings.

I wrote earlier that we have already made big strides towards eliminating the single purpose piece of apparatus from our store rooms. The cylinder and bucket for Archimedes' principle has given way to the oscilloscope and signal generator, both now general purpose tools in the physics department. But they must be equally suitable and equally available to the biologist for example, for demonstrating heart beat or measuring the threshold of hearing. Ripple tanks, ticker timers, Worcester circuit boards, Westminster electro-magnetic kits, all are examples of generalised apparatus required over a period of time for a variety of experiments. This is as it should be. The apparatus should be used as much as possible, so that it can wear out and be replaced within a reasonable time by a more modern equivalent. The trend is obvious too in chemistry. The beam balance—ten to a laboratory and each in a purpose-built glass case—has been replaced by one direct reading balance, preferably a top pan, thus releasing valuable space. Some top pan balances are so robust that they can be wheeled on a trolley from laboratory to laboratory, and once levelled are ready for use. Such an instrument, shared between two or three general science laboratories, will drastically cut the cost of the weighing facility. Even where these balances are provided or are thought to be necessary, on a scale of one per laboratory, it is a more efficient use to concentrate all of them in the one laboratory, when a weighing facility is required. Sad to say, I still hear and read of teachers who, when asked their requirements for a new new school building, insist that there should be a balance room. Fair enough, but let me ask them, is there provision for an apparatus store, shelved from floor to ceiling with just enough space between racks to push a trolley for collecting the equipment? If not, I would rate the latter as the more useful provision for the future, if not for the present day. Are they still insisting on a built-in fume cupboard, or worse, a row of them along one wall, those time-honoured repositories of dirty apparatus and fuming chemicals? If they are, they should see the CLEAPSE[1] mobile fume cupboard, and consider whether in some laboratories at least this may be the answer.

The central store is not a new idea in physics departments. But in the past it was the home of the once-used, custom built apparatus. The Boyle's Law sliding tubes, the constant volume gas thermometers, the coefficient of linear expansion apparatus, all lay there undusted for fifty weeks of the year. The store of today and of the future should be a very different place. Its conception will have been considered when the school was being planned, so that it is next to the workshop where equipment has to be repaired, and so that the laboratories it serves are all on the same floor. It will be the workplace of the laboratory assistant—a different person from the technician—whose responsibility it will be to see that equipment arrives at a laboratory in correct quantity at the right time, and that it is checked for defective or missing pieces when it returns. This involves organisation of the apparatus in trays or boxes so that missing items can be easily spotted. It is a position which should find no dearth of applicants from married women wishing to return to employment as their children grow up, and who aspire to something better than school-cleaning. With a little training they may undertake the cleaning of all glassware and such elementary repairs as the fitting of terminals to broken connecting leads.

The teacher in the comprehensive school, of whom I wrote earlier, faced with four or more classes studying the same topic, has to choose between two alternatives. Either to stock each laboratory so that it is self-supporting except for the custom built apparatus and the larger demonstration pieces, or to have a department built round a central store, workshop, and lecture theatre. In the former, teacher and pupil alike are isolated, each class in its own cell, with little intercommunication. Apparatus is taken out of cupboards and drawers as required, replaced after use and will inevitably tend to be underused. On the second system, the key features are the workshop, store and lecture theatre. The last encourages, in fact necessitates co-operation between teachers, and team teaching. It must not be too large, or some pupils will be too far from the action. It should have writing facility for the pupils, and the visual aids will be concentrated in it, including closed circuit television. This suggests a room to accommodate 50–80 pupils, so that two or three classes may be brought together whenever experiments are to be demonstrated, or for the viewing of a television programme. It does not mean that one teacher does all the work while his colleague has a quiet smoke in the staffroom; while one is doing the talking and the writing, the other is operating the equipment or the visual aids.

Elsewhere, in the laboratories, while one class is in session, the laboratory assistant is loading a trolley in the store with the apparatus required for the next. At the end of a lesson, pupils replace on a trolley the apparatus they have used, this is pushed outside the door and the new equipment brought in. Removing the need to store all equipment within the laboratory itself allows more flexibility in the design of laboratory furniture. Fixed benches with cupboard and drawer space can to some extent be replaced by free standing tables which may be arranged to suit the requirements of the lesson. Practical work can be separated from classroom teaching within the laboratory by having an area with fixed, even tiered seating for writing and discussion. With the blackboard in the middle of the laboratory, rolling in a horizontal rather than a vertical direction, instructions for practical work given and discussed while the pupils are seated at their desks are equally available from the other side of the board when they proceed to the practical work area. Children no longer have to sit sideways on stools, peering over one shoulder at a blackboard which may be 15–20 metres distant, and write on benches which were not designed for that purpose. Like the blackboard, the teacher's demonstration bench is central in the laboratory, and double-sided, so that he may demonstrate to pupils either in the seating area, or at the practical benches. Such facilities as I have described, and of which further details may be found in *Educational Building Notes No. 5*, published in 1965 by the Scottish Education Department and obtainable through H.M.S.O., are to be found in the newer Scottish schools.

Finally, a word regarding the position of the laboratory technician. Teachers who have not enjoyed the services of a technician tend to think "How can we ever occupy his time?" those who have had a technician say "How did we ever manage without him?" The former ought to know how he should not be used. He should not be made to do secretarial work, such as duplicating notes or examination papers. He should not be taught either separately or with a senior class, the theoretical aspects of his subject in order to make him more useful to the teacher; this is the job of his further education college. He should find full time employment in keeping the apparatus in his department in good repair, in constructing bits of apparatus for sixth form projects (a new thing in England, but for the past three years, 50% of our sixth form examination), in developing for the physics teacher new apparatus which may eventually be published in educational journals, and in the production of class sets of standard apparatus.

In case the last may seem strange—why make ripple tanks when we can buy them?—it is worth pointing out that labour and handling charges make up an increasing proportion of the final cost of much of our apparatus. Consider two examples:

firstly the Nuffield physics item 9D, the lamp unit from the energy conversion kit. This consists of three low voltage lamps in holders, mounted on a wooden block carrying 4 mm terminals. The total cost of the materials, at retail prices, i.e. buying singly from Radiospares or even from the educational suppliers themselves is about 45p, compared with £2·35 charged by one firm for the finished article. Labour and handling is thus 80% of the final cost. Nuffield item 107, a trolley runway, costs £6·10 to buy. The blockboard from which it is made costs 14p per sq. ft. With two reinforcing angle iron strips along each side, the cost of materials is 38% of the total. Hence in specific instances, and I believe the number of such instances will continue to grow, it may be equally profitable to buy the materials in bulk and use the laboratory technician to construct the finished article. If this is done in a science centre, maintained by the local authority and wherein trainee technicians spend one or two days per week receiving instruction from a skilled resident technician, the trainees are not only being taught the practical aspects of their job, they are making apparatus which will finally be used in their own school and in the maintenance of which they will have a personal interest. Such science centres are already in existence in the larger local authority areas in Scotland, sometimes specific to science, sometimes in combination as a teacher resources centre, along with visual aids, language laboratory workshop etc., and some are training their technicians in the manner described.

At the other end of the scale the same trend is evident. In recent months, following on their merger with Baird and Tatlock, W. B. Nicholson have closed their factory; Griffin and George have ceased production of many items in their vast range. This trend introduces one more link in the chain between manufacturer and user of the apparatus, increasing handling costs, and delivery dates. Why, for instance, should locust egg tubes cost 20p from one supplier, 5p from another, when a suitable container can be bought for 4p from toyshops selling bubble blowers, and with a cap and full of liquid to boot? Many of the designs we have published from the Centre[2], where the materials cost only shillings, can in fact be made only by laboratory technicians. Technical representatives who have seen them agree that they would be hopelessly uneconomic to manufacture commercially. Our Brownian motion smoke cell[3] is a case in point. The schools market is still essentially a cottage industry with the labour force making batches of this, that and the other piece of apparatus. We can never expect the benefits of mass production like, for example, the motor car industry. Without such advantages, are there not sound social reasons why the technician should not be employed in his own home, rather than concentrate the labour in an over-populated industrial area?

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SI AND ITS POSSIBLE EFFECTS ON THE TEACHING OF PHYSICS IN SECONDARY SCHOOLS

R. Schofield

IN 1965 the government decided to metricate weights and measures used in this country. In itself such a decision was of little consequence to those of us concerned with the teaching of physics in schools. However, it was also decided to change to that form of metricated units called the system international (SI) and this decision is of far greater importance. SI was approved by the Conférence Générale des Poids and Mesures in 1960 and is obviously going to become the universal currency of science and commerce. It is true that, even at this early date, several bodies have shown marked reluctance to adopt that portion of SI which applies to their own special field. The Triple Commission of Spectroscopy, for example, is unanimously in favour of the continued use of the ångström, a non-SI unit. In spite of this it is increasingly clear that, apart from its use in such specialist fields as advanced spectroscopy, SI will be widely, if not universally, adopted. In the light of this evident trend schools have little choice but to adapt their teaching to the SI units. Already examining boards have announced their intention to move to SI by stated dates, usually 1971 or 1972, and "SI editions" of the more popular text-books have been written and published.

It is the intention of this short paper to consider the implications of these changes for those teaching secondary school physics. It is not proposed to discuss the SI units as such and those who wish to learn more about them will need to study one of several very accessible accounts.[1] Those who do this will need to be on their guard since they are exposing themselves to some risk. There is a small but definite possibility that they may join the ranks of those who have become addicted to the study of units. Just as in the middle ages the schoolmen argued with erudition as to how many angels could be accommodated on the head of a pin, so their latter-day descendants discuss with equal solemnity the status of the litre or the anomalous nature of the kilogramme. It is only too easy to be so beguiled by discussions of this kind that one becomes forgetful of the underlying physics.

Although papers have been published in *The School Science Review*, *Physics Education*, and elsewhere, on the consequences of the proposed change, it remains true that, as yet, many teachers have given but little thought to the implications of the change in their daily work. There is no doubt that if pupils are not to suffer as a consequence of a change made for reasons other than educational, then in-service courses must be provided on a very considerable scale. It is a matter for regret that the decision was taken without consultation with bodies such as The Association for Science Education whose members will have to bear the brunt of its consequences in secondary schools. This is not to say that such bodies are opposed to the change; indeed the advantages to be gained are considerable, not least from the fact that SI is coherent and does not depend on a number of arbitrary constants. Rather it is a plea that when changes are introduced which will involve large numbers of teachers in a fundamental rethinking of much of their work, they should be consulted at an early age.

Possibly the facet of the change which will prove most troublesome to the practising physics teacher, will not arise from a problem associated with a fine point of physics but from the difficulty of arranging his lessons without the aid of a text book written in SI. It has been held, for example, by Spurgin,[2] that such difficulties are not troublesome. We should be careful, however, of drawing conclusions too readily from the experience of talented and experienced teachers working with able students. One has only to think of an average fourth year class dealing with the simple theory of machines under a teacher who talks exclusively in the language of SI and who is using a text book written in a mixture of Imperial and metric-technical units. I am not sure that the final outcome would be altogether a happy one.

As already mentioned some books employing SI have been published. In the absence of clear directives from examining boards the authors have had to make guesses as to how some sections of the work will be treated. The new, SI edition of Abbott's famous book *Ordinary Level Physics*, for example, uses the gramme-force as the force unit throughout much of its treatment of elementary mechanics and hydrostatics. There are sound reasons for adopting such a course but a book written in this way can hardly be described as an SI edition. It is probable that until a kind of case law for the use of SI in school physics has been built up over a period of several years, confusion of this kind will be common. This is a pity since it could have been avoided and because pupils will suffer in the transitional period.

As an example of the way in which a case law of use is built up consider that part of our school work concerned with electricity and magnetism. If a new examining Board were to tell us that it proposed to set its examinations at 'A'-level in the c.g.s. system we at once would know that the system used would be an unrationalised three quantity system using mixed esu and emu units. The questions set could of course be *answered* in any c.g.s. system; they are *set* in a *particular* system. This has become so institutionalised that many pupils (and their teachers) think it is *the* c.g.s. system. It has become part of what I have called the case law of 'A'-level examining. So much is this the case that it is amusing to consider what the reaction would be if our imaginary new Board were to set questions in, say, the coherent Gaussian form. Many teachers have come to rely on the uniformity of examining practice which follows from the acceptance of this case law. The introduction of SI may mean that for a time at least, it can no longer be counted on. The very valuable synopsis of the published intentions of the Boards with respect to the introduction of SI which was published in the September 1969 edition of *Education in Science*, showed that whilst some Boards appear to be moving to a position of exclusive SI others intend to retain (on very rational grounds no doubt) a number of Imperial Units. Yet other Boards intend to retain non-SI units, more particularly the calorie in certain examinations. It is my view that there is a considerable need for a greater degree of uniformity on SI as between one Board and another than has been common in the past. There has been, we know, a specific wish and desire to serve the needs of the teachers in schools. There is no doubt that the whole structure of 'O'-level and 'A'-level examining has been designed to ensure that the examination shall be one acceptable to the schools and in a very real sense the examination has been influenced by those working in the schools.

With the advent of SI and of the possible moves towards more uniform conventions in the world of science generally, which even if opposed can hardly fail to make some progress, it is probable that examining boards should pay more heed to the needs of the scientific community and this might mean that Boards will have to adopt common policies rather more often than has been necessary in the past.

Although many specific questions will arise as the units are used in a school physics course, not least in considerations of which is the best preferred multiple or sub-multiple of a basic unit to use in given cases, it is the r.m.k.s.a.[3] in electricity and magnetism which will be of greatest concern.

The introduction of the newton will at least mean that we will teach mass and weight to our pupils without seeming to be obscurantist. The difference between the concepts will be obvious to all. Although some think that the newton is a difficult unit to teach across the whole of the ability range, there can be no doubt that the teaching of gravitational attraction will be much easier than it has been in the past. Probably the most straightforward approach will be to avoid, at least in the earlier stages of a course, the acceleration due to gravity and instead to teach in terms of a field of force, which on the earth happens to be about 9·81 newtons per kilogramme, but which has a different value on other planets.

At its first introduction, the newton is simply the force which extends a spring balance until it reads one newton. Many of our pupils, perhaps the majority, will never know how the unit is defined. This is no more cause for concern than the fact that most users of the ampere have not heard of infinitely long parallel pairs of current carrying conductors placed one metre apart. It is probable that the fact that both mass and force appear to be defined in quite an arbitrary manner when first met will help our pupils to avoid confusion between the concepts.

It would be too much to hope that we will in future avoid saying that we buy butter by weight. The fact, however, that the weight of butter will be given in kilogrammes, an obvious unit of mass, and not in newtons will help us in our desire to show that this use of "weight" is wrong. A consideration of what we should expect to buy in Sainsbury's Lunar Branch, will help to reinforce the truth of this fact.

Although SI should be a positive help with mass and weight the same cannot be said when teaching Archimedes' principle. It is probably because of the complexities that arise here that Abbott and others have decided to retain the non-SI gramme-force in their books.

Consider a simple question asking us to find the specific gravity of a body which weighs 56 gf in air and 50·96 gf in a liquid of specific gravity 0·72. This could appear in the following form when SI has been introduced:

Find the density of a body which weighs 0·560 N in air and 0·5096 N in a liquid of density 0·72 kg dm^{-3}; take the earth's field of force to be 10 N kg^{-1}.

Now, there is nothing really difficult here, but there is every likelihood that our younger pupils will be very confused and it is easy to understand the motives of those who have decided to retain the gramme-force.

Some readers may be wondering why it is necessary to consider Archimedes' principle at all, for in some revised syllabuses it does not appear, and it may be argued that it should be allowed to die a natural death. It seems certain that either we will have to retain non-SI units or we will have to postpone the teaching of Archimedes' principle and the like to a much later stage than is now customary.

The absence of the calorie from the SI units of energy is probably going to be an important cause of change from our more traditional ways. It is obvious that any international body of professional scientists would not wish to include a redundant and non-coherent unit like the calorie. Decisions which are sensible within one context may be less than obvious in others. Some experienced teachers of physics feel that this is just such a case. Traditionally we have introduced heat through the calorie, using a teaching approach dependent on that unit. Quantity of heat so defined is being retained until at a later stage the mechanical equivalent of heat has been introduced and the original concept widened. If in future we are not able to use the calorie a whole teaching approach is in danger. It is probably because of this and similar considerations that some examining boards have decided to retain the unit, or its multiple, the kilocalorie. Especially is this the case in chemistry where the calorie is the unit for all forms of energy. This is almost certainly a mistake, since the necessity to teach heat without the calorie may prove to be just the stimulus we need to cause us to rethink our traditional development and to teach heat in a way that is more soundly based and likely to lead to fewer difficulties at a later stage.

Can there be any doubt that we have been presenting our young pupils with a theory which is essentially a caloric theory of heat? When I recently questioned some twenty-five young science graduates they all admitted that they always thought of heat as a 'substance' which ran into and out of bodies filling it to 'depths' which were indicated by the observed temperature change. When necessary they switched to another level of thought and regarded heat as a form of energy. This experience, which is similar to my own, arises from the way in which the use of the calorie as an energy unit enables us to introduce heat in a quantitative manner at a very early stage of a school physics course.

If we teach a caloric theory, as I believe we do, it is probable that we are failing to teach effectively. Those pupils who only study to C.S.E. or 'O'-level attain a less than satisfactory picture of what is meant when we say that heat is a form of energy. Further, those of our students who later pass on to a formal study of thermodynamics with a quasi-caloric view of heat, find more than passing difficulty with even the first law since it is difficult for them to see quite what is being said which makes the statement so very important.

If the absence of the calorie from SI is taken as an opportunity to refashion the traditional approach to the teaching of heat, we may well gain far more than the use of a coherent set of units. Quantitative heat may have to be taught later than has been the convention, but this need not preclude much of the traditional qualitative material being presented exactly as it is now. What is essential is that the pupils should have experienced many examples of energy transformation using apparatus similar to that developed for the Nuffield Energy Kit. A form of the rotating drum apparatus developed for the determination of the mechanical equivalent of heat, can then be used to show that mechanical energy appears to enter a body and cause a rise in temperature. The energy is now described as a change in the *internal energy* of the body which is an obvious and natural name. It then remains to demonstrate that energy transformations of this kind are such that for a given body the rise in temperature seems to bear a constant ratio to the energy input, *whatever the kind of energy transformed.* This fact leads to the definition of *heat capacity* and *specific heat capacity* and of course 'takes the place' of the traditional mechanical equivalent of heat. When the changes of temperature consequent on change of internal energy have been fully covered, and not before, it is time to introduce heat as the name given to energy moving between bodies at differing temperatures. Since this energy is accompanied by temperature changes when it is transformed into internal energy and since the specific heat capacity enables us to calculate at once the rise in internal energy it is natural to measure heat in energy units, the joule or one of its multiples. Dr. J. Warren, of Brunel University, has long argued against allowing our pupils to talk of the quantity of heat *in* a body. Now that the calorie need not be used as an energy unit, it is possible to teach the physics of temperature, change and heat transfer in such a way that the term, quantity of heat in a body, would seem nonsensical.

The outline given above is old hat and offers little that is new. On the other hand, able and experienced teachers of physics have been heard to state that they find great difficulty in seeing how heat may be taught to children without the calorie since it will not be possible to teach the mechanical equivalent and without that, the measurement of 'heat' in joules is meaningless. It is to be hoped that the introduction of SI will motivate us to give our method of teaching heat the careful examination it undoubtedly needs.

In more elementary work, we will almost certainly continue to define temperature scales in terms of the usual fixed points; this indeed is the course followed by Abbott in the book mentioned above. It is also probable that we will continue to use the Celsius scale, but mercifully the Fahrenheit scale is surely about to disappear from school physics. At sixth form level we will need to consider the SI definition of the temperature unit known as the kelvin. Almost all sixth form books now in use write in terms of temperature scales defined by:

$$t = \left[\frac{P_t - P_{ice}}{P_{steam} - P_{ice}} \times 100\right] {}^{\circ}\mathrm{C}$$

It is then usual to show how one such scale, the ideal gas scale, is used. At a later stage of his career, the student learns of the thermodynamic scale and it is seen to be equivalent to the ideal gas scale. The definition of the kelvin begins, however, with the statement that it is the unit of thermodynamic temperature. Further it is the fraction 1/273.16 of the temperature of the triple point of water. How can we make sense of this in school Probably we will continue to use the concept of the ideal gas scale, but instead of the defining equation for temperature

$$T = \left[\frac{P_t - P_{ice}}{P_{steam} - P_{ice}} \times 100 + 273.15 \right] K$$

we will now write:

$$\frac{T}{P_t} = \frac{273.16\ K}{P_{tp}}$$

where P_{tp} is the magnitude of the property of the gas at the triple point.[4]

Little difficulty should arise but teachers will need to be on their guard against the unthinking use of questions taken from past papers which will now only serve to mislead their pupils.

Electricity and magnetism in the sixth form will be a rather different subject for many of us, than it has been in the past. It is true that many teachers have been using an m.k.s. approach and the first of the Association for Science Education's reports on the teaching of electricity which recommended such a usage, was published in 1954. There is, however, considerable difference between a teacher who moves over to a new system of units after a good deal of thought, having decided that on balance it is the better system for him to use with his pupils, and a teacher who has to change to a system about which he knows little, or worse, with the use of which he does not agree. More than a few teachers are going to be in the latter group during the next few years.

It will be possible to approach the change in one of two ways. Some will decide that such a change needs thorough preparation, and they will read widely on the subject. Others will choose a text book which they believe to be sound and will simply follow its approach. In most such situations, it would be normal to commend the first course of action rather than the second. In the present case, it is not quite so clear cut a position. A lot has been written about r.m.k.s.a. and much of it is confusing at first reading. There is something to be said for advising a teacher newly changing to r.m.k.s.a. from the usual c.g.s. dual system used in schools, to thoroughly familiarise himself with one particular presentation of m.k.s. before venturing into the diffuse, and sometimes polemic, literature.[5]

It should be made clear that until 'O'-level, there is no problem, since the practical units commonly used are all part of SI. It is when the teacher begins to treat electric and magnetic fields of force that the complexities arise. The A.S.E. report mentioned above included the details of many ingenious experiments which it suggested should be used in any presentation of the subject which employed r.m.k.s.a. Manufacturers quite properly, began to sell versions of the apparatus necessary to carry out these experiments, and not unnaturally called it apparatus for the teaching of m.k.s. in electricity and magnetism. It is now quite common to find this referred to as 'm.k.s. apparatus'. The danger arises when the teacher feels that if m.k.s. is to be taught it is necessary to use one or other form of this apparatus since it is in some way intrinsic in the approach, Far be it from anyone to imply that m.k.s. *should* be taught without the aid of this apparatus, but it needs to be clearly understood that it is no more or no less necessary to carry out these experiments when using an m.k.s. approach, than it is when using the c.g.s. approach. If it has not been felt necessary to use this apparatus when developing a c.g.s. approach to electricity and magnetism, an m.k.s. approach *can* be taught in exactly the same way. Physics is physics whatever system of units is used and we cannot by changing our units in some way, change the conceptual structure that we have to build up.

At about the same time that the C.G.P.M. was adopting r.m.k.s.a. as the SI system of electrical units, much thought was being given to the teaching of electrical and magnetic fields. It is a little strange that this had not been done earlier. If it is of importance to discuss the relationship between **B** and **H** in one system of units it must be of interest to look at it in another. The absence of discussion was probably because of the little appreciated fact that **B** and **H** have differing dimensions and obviously differing units in m.k.s., whilst in c.g.s., although it has been customary to use different names, the gauss and the oersted for the units in which **B** and **H** are expressed, they are alike dimensionally, Indeed Purcell in his book in the Berkley Physics Series makes the point that it is as though we measured the radii of circles in cm and the circumferences in a unit called the arc which is one cm in length. It is quite possible to devise an m.k.s.a. system in which **B** and **H** are similar dimensionally, as has been done by Feynman in his well-known text. However, SI uses quite different units, the tesla for flux and the ampere per metre for field strength.

The Association for Science Education published a second report on the teaching of electricity and magnetism in 1966. Unfortunately, as it has turned out, it adopted the policy of giving all the relationships in its suggested approach in such a way that by the substitution of suitable values for certain constants in the equations it is possible to retrieve the relationships of either a rationalised or unrationalised form of both the c.g.s. and m.k.s. systems. Because, perhaps, of the resulting complexity the report has not been given the attention it deserves. Since schools are very soon to have no alternative to teaching a rationalised m.k.s.a. approach the suggestions contained in the report would have been far more meaningful if it had been written in r.m.k.s.a. alone.

The more far-reaching of these suggestions are that **B** and not **H** should be taken as the primary field vector of magnetism and **E** rather than **D** in the case of electric fields, and that it is sensible to avoid the treatment of permanent magnetism in school physics. The first of these suggestions is in line with the development in many present day American texts and follows from the adoption of the Summerfeld convention in the treatment of magnetic moment.[6] Its importance here is, that some texts published in this country following the 1954 report, followed the Kenelly convention favoured by that document and treat **H** as though it is the cause of **B**.

It is obvious, that if care is not taken we will abandon a situation in which all candidates and examiners use the same convention for a situation in which anarchy reigns. This must be avoided at all costs. One can conceive of several ways in which this might be done, but the simplest is for a Board to issue a much fuller description of the assumptions it proposes to make when setting questions in electricity and magnetism at 'A'-level.

REFERENCES

1. See for example:
   (i) *SI Units, Signs, Symbols and Abbreviations.* The Association for Science Education, College Lane, Hatfield. 6*s*.
   (ii) *The use of SI units.* British Standards Institution, Sales Branch, 101-13 Pentonville Road, N.1. 4*s*. plus postage.
2. Spurgin, C. B., *Physics Education*, January 1969.
3. r.m.k.s.a.—rationalised metre kilogramme second ampere.
4. 273.15K is the temperature of melting ice at standard pressure whereas 273.16K is the temperature of the triple point of ice.
5. See for example the following; there are many others: W. F. Archenhold, Electromagnetism using SI units. *Physics Education* **1**: 171, W. James, Conventions and Nomenclature in electromagnetic theory, *Physics Education* **3**: 66, R. G. Chambers, Letter. *Physics Education* **3**: 220.
6. An accessible and clear account of these matters may be consulted in P. Halligey. The Evolution of MKS Electrical Units: Effects on the teaching of electricity. *Contemporary Physics*, **7** : **3** : 161.

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SCIENCE IN A COMPREHENSIVE SCHOOL

D. E. Yates
D. N. Underwood

Introduction

We are not at all sure that we know the best way of teaching science to children of all ranges of ability. We are sure from experience, some of it bitter, that, presented with the academic organisation in many of our schools, neither traditional methods nor unadulterated Nuffield schemes are suitable. Schemes that we have devised have met with modest success. Whilst we would not wish to extrapolate from our limited results to predict ultimate satisfaction, we think our efforts are worth recording. No originality is claimed. Much is owed to Mr. P. Kidger, now deputy head of the Deanery High School, Wigan, and modifications of the scheme outlined here under the heading 'The initial years' are in operation at a number of comprehensive schools in Kingston upon Hull. The schemes outlined thereafter apply to Sir Leo Schultz High School.

Academic organisation

The schools involved in schemes similar to ours are completely unstreamed. However, in years 1, 2 and 3, several forms have common timetables so that the teaching unit is, either, 120 or 60 pupils. This unit is called a population and contains the whole range of ability. To each population is attached an appropriate number of teachers.

The benefit of such a timetable is that each head of department can decide for himself the best method for the teaching of his subject, and has the following options at his disposal:

(i) Children can be placed in sets according to their ability in an individual subject

or (ii) They can be taught in mixed ability groups

or (iii) Various types of team-teaching are possible.

We have found that in years 1 and 2 mixed ability teaching is feasible and indeed has much to commend it. With large populations some economy of effort is possible when giving elaborate demonstrations or showing films.

Excerpt from Year 2 timetable

<table>
<tr><th rowspan="2">Form</th><th colspan="7">Period</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>2A1</td><td rowspan="2">Music</td><td rowspan="2">Geography</td><td rowspan="4">French</td><td rowspan="4">English</td><td colspan="2" rowspan="2">Science</td><td rowspan="4">Mathematics</td></tr>
<tr><td>2A2</td></tr>
<tr><td>2B1</td><td colspan="2" rowspan="2">Science</td><td rowspan="2">History</td><td rowspan="2">Music</td></tr>
<tr><td>2B2</td></tr>
</table>

Excerpt from Year 3 timetable

<table>
<tr><th rowspan="2">Form</th><th colspan="7">Period</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>3A1</td><td colspan="2" rowspan="4">Science</td><td colspan="2" rowspan="4">Games</td><td rowspan="2">History</td><td rowspan="4">Mathe-
matics</td><td rowspan="2">Music</td></tr>
<tr><td>3A2</td></tr>
<tr><td>3B1</td><td rowspan="2">Religious
Education</td><td rowspan="2">Geography</td></tr>
<tr><td>3B2</td></tr>
</table>

In year 3, when lessons have an increased theoretical content, some setting may become desirable and the least able withdrawn to follow a modified course. Thus, with a population of 120 having six periods of science per week, the following arrangements could be adopted.

	1 and 2	3 and 4	5 and 6
Set 1	Physics	Chemistry	Biology
Set 2	Chemistry	Biology	Physics
Set 3	Biology	Physics	Chemistry
Set 4	(.............. General Science ....)		

At the end of year 3 we believe children should opt for various subjects. *All* should study science but there must at the same time be the possibility for potential scientists to study physics, chemistry and biology as separate disciplines.

The initial years

Our aim is that in the initial years all pupils should enjoy their science and that it should not become merely a process of accumulating a large number of facts.

In any new school it takes a number of years of trial and error to achieve one's ideal in terms of syllabus content and teaching methods. At first we believed, as many science teachers still do, that we could teach a somewhat diluted grammar school science course to our mixed ability groups. It soon became obvious that we needed to rethink our methods completely and even to reject class teaching as a basic technique.

In teaching mixed ability groups one must enable each pupil to progress as fast as he is able, at his own level of ability. Overmuch emphasis must not be laid on the acquisition of factual information. These aims are impossible to achieve using formal teaching methods. With such methods the less able pupils soon become bored; they forget what they are supposed to be doing in an experiment and quite often do the wrong thing, no matter how simple the experiment may be. Among less able pupils this frustration leads to discipline problems. On the other hand the able pupils are soon ahead and waiting for the others to catch up.

Worksheets are an obvious solution. But this is not as straightforward as it at first seems. Mixed ability groups in the early years inevitably contain non-readers. At Sir Leo Shultz High School the non-reader may be removed from certain lessons to have additional work in writing and reading. However, in science, this never involves the removal of more than one or two per group of 32 pupils, still leaving an almost complete range of academic abilities.

Under these circumstances, worksheets must be simple enough fo[illegible] pupils to read and understand. They must allow the more [illegible]pils to be fully extended, whilst still motivating the less a[illegible]

Our own worksheets, of which two examples are given in the Appendix to this article, aim to do this as follows: all pupils, working individually, attempt the same basic experiments, using the same worksheets. As a follow-up to each experiment or group of experiments, the worksheets contain additional work or 'research'. This may consist of further experiments or 'finding out', and is designed to enable pupils to study a topic in more depth and detail. This work is normally allocated to the abler pupils after they have completed the basic experiment(s). The allocation of this is left entirely to the judgment of the individual teacher.

It should be mentioned at this stage that the science taught to years 1 and 2, using such worksheets, is a combined science course with topics integrated wherever possible and with one teacher per group. The syllabus is divided into sections, each containing six to eight experiments. These are set out round the laboratory as a 'circus'. It is inevitable that some experiments must be done before others, e.g. a study of the Bunsen burner (see Appendix 1), before it is used in other experiments. This difficulty may be overcome by doing such experiments on a class basis.

How are the laboratories and apparatus organised in such a scheme? In any particular year all groups use the same laboratory. When a series or 'circus' of experiments is being attempted, the laboratory is set out with a number of working places for each experiment. This will normally give approximately 40 working places. Since groups from other years do not use this laboratory, the apparatus may be left out for as long as it is required. Each laboratory also contains a suitable library of books which may be used for 'research' or background reading.

All the pupils attempt each of the experiments set out. The aim is that at the end of this stage the slowest pupils will have completed the basic experiments only, but the ablest pupils will have done the experiments plus the additional work and 'research'. There will also be some pupils who have completed the basic experiments plus the easier parts of the additional work.

Demonstration experiments cannot be avoided. Some of these are done by the teacher as required at convenient points in the course, usually at the end of a series. For others, one set of the apparatus is laid out in the laboratory, again with a suitable worksheet, and groups of pupils are asked to do the experiment as required. Obviously this latter method cannot be used for such experiments as the simple mercury barometer.

At the end of each series of experiments, every pupil is given a summary sheet of the basic information required. This is then used as a basis for a discussion period. A test is then set. Since the same test is set to all pupils, it is based only on the common work done. The questions set in the test may be of the following nature:

1. Diagrams to complete and label
2. Sentences to complete
3. Multiple choice

As well as the test marks, the teacher keeps a record of the grade allocated for each experiment performed and, if done, the grade for the additional work or 'research'. The marks and grades are used as a form of continuous assessment, no examinations being set at the end of the year.

One of the main problems which arises in the teaching of mixed ability groups is the setting of homework. In our scheme homework is set to all pupils and is allocated by the teacher on an individual basis during the lesson preceding the homework night. For the less able the homework would probably be, 'finish writing-up your experiments', for the able who will have done this already during the lesson, it would probably be selected from the additional work or 'research'. The homework is then checked and graded.

The general scheme outlined above is, as yet, by no means perfect. Problems still arise and experience has shown that many of our worksheets need to be revised. This is in the process of being done, as will be explained later. We can, however, without hesitation, make the following points:

(1) Using this scheme has brought us closer to solving the problems of mixed ability teaching than anything we have tried previously

(2) Each pupil is able to work at this own pace and attain his own level of ability

(3) The response of the less able pupils is much better than previously. Many of these pupils ask if they may attempt the additional work or 'research' in their own time. Provision is made for this by having supervised 'extra work' sessions after school.

(4) Able pupils show an extraordinary avidity for this type of work and voluntarily spend many hours on 'research' topics. The volume of good written work produced by a small proportion of such children exceeds anything encountered by us in schools using traditional methods.

The role of the teacher in individual learning

The teacher has already done a considerable amount of work before the course begins. Such a course requires a great deal of organisation and much time must be spent in the preparation of worksheets. These sheets are produced by teachers working in small teams and are then used by all those involved in the teaching. In the classroom the teacher is kept very busy. Individual learning is a most demanding experience. The teacher is always occupied; checking work, allocating new experiments, allocating homework, and chivying the slow and the time-wasters.

From the teacher's point of view, the main advantage in individual learning is the improvement in the pupil-teacher relationship. There is much more personal contact during discussion of individual difficulties. Discipline generally becomes less of a problem. Much less time is spent addressing the class as a whole.

Individual learning does have disadvantages; the main one is that of very large groups. In our own case, groups are always larger than 30. There is also a great pressure on the laboratory assistants, since one must always be available in the laboratory to replace apparatus, check quantities of chemicals, splints, etc.

Although the first year of trying out such a scheme was very hectic, by the end of the year all staff preferred teaching science to mixed ability groups by individual learning to conventional teaching.

After the initial years

The school has now become a Senior High School and in the future the main intake of pupils will be at the age of thirteen-plus. When this occurs we shall have very little, if any, knowledge of the abilities of our new pupils or of the science they will have been taught. Syllabuses have been recommended to the Junior High Schools, but there is no guarantee that these will be followed. It will, therefore, be necessary to ensure that, during their first year in the Senior High School all pupils have at least covered the basic topics in science.

On entering the school pupils will be placed in mixed ability groups and will follow a scheme very similar to that outlined above. It will be taught as combined science with one teacher per group. The emphasis will again be on individual learning. The syllabus and worksheets have already been modified. In the new scheme all writing and recording of results will be done directly on to the worksheets themselves which will be retained by the pupils and filed. It is hoped that, in the relatively short time available, every pupil will achieve a good grounding in all aspects of science.

The pre-examination years

In previous years, in our own school, pupils who intended to leave school at the age of 15 were segregated from those pupils who wanted to remain at school to the age of 16 and beyond. Whilst the latter groups followed examination courses, the former followed special 'non-academic' courses in each subject. This was not entirely successful and had the main disadvantage of bringing together all the potential discipline problems. This scheme has now been discarded.

Towards the end of their third year (in a Senior High School this will be their first year) all pupils make the choice of subjects they wish to take in their fourth and fifth years. Since there are a number of options in science, much guidance is given by members of staff. Our main aim is that pupils should follow a science course best suited to what they wish to do when they leave school. But, of course, the ability of the pupil must also be taken into consideration.

All pupils in their fourth year (the second year in a Senior High School) must take English, mathematics and science, or what is termed the 'Basic Course'. Hence all pupils have four periods of science per week on their 'Basic Course'. The year group is divided into two populations of approximately 180 pupils each. One of these populations is sent to science at any one time and pupils study one of the following:

Physics: leading to a G.C.E. or Mode 3 C.S.E. examination

Physical science: leading to a G.C.E. or Mode 3 C.S.E. examination

Combined science: leading to a C.S.E. examination for some pupils

Rural studies: leading to a C.S.E. examination for some pupils

For the most able pupils the choice will lie between physics and physical science. The choice would be physical science for pupils who wish to take one science subject only or who wish to take biology as a further science subject. For the least able the choice will lie between combined science and rural studies.

It will be seen that chemistry and biology are not included in the science on the 'Basic Course', They may, however, be taken at other times as options set against other subjects. Both of these may lead to a G.C.E. or C.S.E. Mode 3 examination. The arrangement of choices is such that the able pupils may, if they wish, take all three science subjects. One point to be made clear is that no pupil is allowed to take physics as his only science subject. It is also obvious from the arrangements that it is impossible to take chemistry or biology as an only science subject. The possible combinations of science subjects are as follows:

Physics, chemistry and biology
Physics and chemistry
Physics and biology (not recommended)
Physical science and biology
Combined science
Rural studies

Some of the science courses mentioned lead to a Mode 3 C.S.E. examination. This means that both the syllabuses and examinations are set by the school, although the final examination papers are moderated by the local examination board. The use of a Mode 3 C.S.E. examination is desirable wherever possible because it enables one to have a basic, common course in a particular subject for much of the fourth year. This allows selection for the G.C.E. and C.S.E. courses to be delayed as long as possible.

It is inevitable that some of the pupils following the various courses will:

(1) leave at the end of the fourth year. This number, however, is becoming smaller each year

(2) leave at the end of the fifth year without taking an examination

(3) not reach the examination standard at the end of their fifth year, but will remain to take it at the end of their sixth year

In organising our fourth year courses we have kept these points in mind, as well as the fact that fairly soon all pupils will remain at school until the age of 16.

The more able pupils will follow courses in physics, chemistry, biology, or physical science. Generally, each of these subjects provides sufficient pupils to make setting possible, although the sets will follow the same basic course at least to the end of the fourth year.

Use is still made of worksheets in these courses (see Appendix I and II), but these tend to be mainly instructional in nature and are used on a class basis.

Apart from the most able there remains a number of pupils of fair ability who are certainly capable of an average C.S.E. pass in general or combined science. These pupils are integrated with the remaining non-academic pupils, i.e. those who will not take an examination, although all pupils leaving the school obtain a certificate indicating that they have completed specific courses. Some of these pupils take rural studies, but the majority will follow the combined science course. This course has been designed to suit a range of abilities below that of the most able and, we hope, to motivate the least able pupil.

The combined science course is based entirely on individual learning and again makes use of worksheets. The syllabus has been divided into a numbr of sections, each section, e.g. air, water, light etc. having its own set of worksheets. These contain details of experiments, projects and guidance to note-making. Each pupil is provided with a set of worksheets covering the section of work. The necessary apparatus is made readily available in clearly labelled boxes and cupboards. Each laboratory used for the scheme contains a suitable library of books which are used for reference. Again a problem arises with experiments which are normally done as demonstrations. Because the laboratories used for this scheme are also used by other groups, the apparatus cannot be left set-up permanently. Such experiments are therefore set-up in a large preparation room. As the pupils reach such an experiment in their section of work they are sent to the room, where the experiment is demonstrated by a member of staff. It is therefore necessary to have this room supervised at all times.

As a pupil completes a section of work he is given a summary sheet which he must learn. He then answers questions from a revision sheet, which is done as a test. Grades are given for the section of work completed and for the revision test. On completion of the revision sheet the pupil is allocated to another section of work. Although the majority of the sections are academic, some non-academic ones, e.g. cosmetics, are gradually being introduced. These are based mainly on projects and are allocated to those pupils who will be early leavers or who will not be taking an examination.

At the end of the fifth year many of the pupils following this course will take a C.S.E. examination, the school assessment being based on the work and projects completed during the previous two years.

Beyond the fifth year

In comprehensive schools it has been found that ever-increasing numbers of pupils are staying at school beyond the age of 16. For many this is not to enable them to follow Advanced Level courses, but to increase, or even to gain their first, G.C.E. 'O' level passes.

In science, this means that many pupils, having gained a pass at C.S.E. level, will spend an extra year attempting to gain a G.C.E. 'O' level pass.

The content of our combined science course has been chosen so that, with an extra year's study, some of these pupils will be able to take a G.C.E. 'O' level examination in physics with chemistry.

It is also inevitable that more and more pupils will wish to stay on at school to take Advanced Level courses—not with the aim of obtaining an Advanced Level pass, but of merely completing a 'broadening' two year course. Much re-thinking of traditional sixth form teaching methods must now take place.

D. E. YATES obtained a first class Joint Honours degree in physics and chemistry at the University of Hull. He began his teaching career in the physics department of Archbishop Holgate Grammar School at Barnsley. After three years he was appointed head of the physics department of Robert Richardson Grammar School, Ryhope, and in 1966 was appointed head of the science department at Sir Leo Schultz High School, Hull. In January 1971 Mr. Yates was appointed deputy head of South Hunsley School.

D. N. UNDERWOOD is a graduate of the University of Leeds. After a short period in industry he taught at Blundell's School, Tiverton; Bristol Grammar School; Malet Lambert High School, Hull (head of science department) and at Sir Leo Schultz High School, Hull. (deputy head). He is now headmaster of Sydney Smith High School in Hull. Mr. Underwood is author of *Chemistry*, first published by E. Arnold (publishers) Ltd., in 1959, latest edition 1970.

APPENDIX

I. Specimen Work Sheet A (used in year 1)

Experiment 1

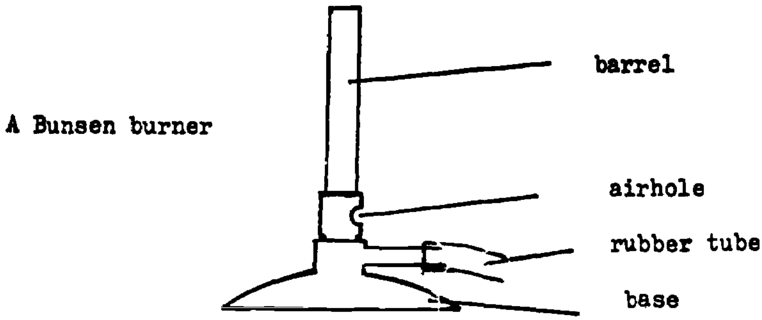
The Bunsen Burner

In science it is often necessary to heat things. Usually we use a Bunsen burner to do this.

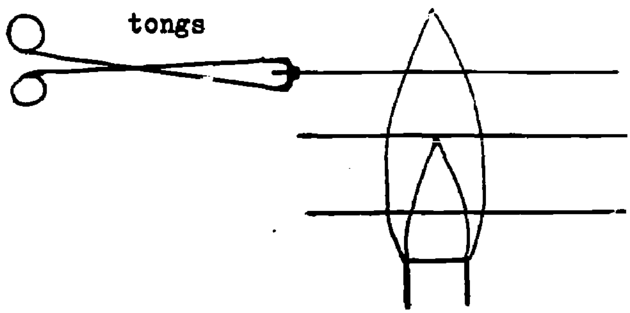
Apparatus: check that you have the following:
A Bunsen burner, an asbestos board, a pair of tongs, a square of asbestos paper.

Instructions:

1. Examine the Bunsen burner carefully.
2. Connect the Bunsen burner to the gas supply by means of the rubber tube, and stand it on the asbestos board.



3. Close the air hole. Turn the gas fully on and light the Bunsen burner at the *top*.
   What does the flame look like?
   What colour is it?
4. Open the air hole a little.
   What colour is the flame now?
5. Open the air hole fully.
   What colour is the flame now?
   What else do you notice?
6. Hold the piece of asbestos paper in the tongs and, in turn, place it for a few moments in positions 1, 2 and 3 in the flame.
   Notice what happens to the asbestos paper in each position.



Which part of the flame do you think is the hottest?
In which part of the flame does there seem to be no heat?

Additional work:

The following should only be done on the instructions of your teacher:
Find out what you can about Robert Bunsen, the inventor of the Bunsen burner.

II. Specimen Work Sheet B (used in year 1)

Experiment 13.—How can we obtain pure salt from rock salt?

Apparatus: check that you have the following:

A Bunsen burner, an asbestos board, a tripod, a gauze, a small beaker, a glass rod, an evaporating basin, a filter funnel, filter paper, a flask, some rock salt.

diagram 1

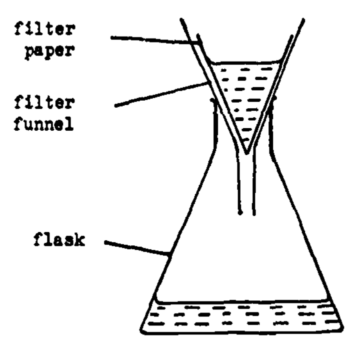
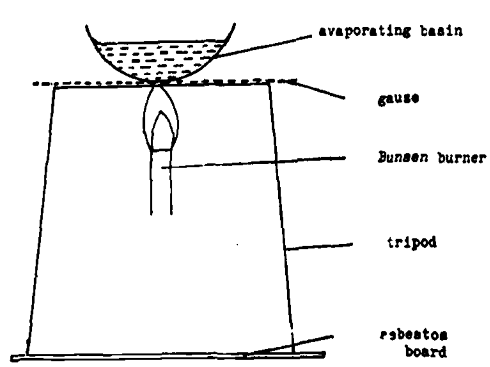


diagram 2



Instructions:

1. Place about half an inch of water in a small beaker.
2. Take enough rock salt to cover a penny. Add the rock salt to the water in the beaker.
3. Stir the water well using the glass rod.
4. Fold a filter paper (ASK YOUR TEACHER HOW TO DO THIS), and place it in the funnel.
   Place the funnel in the neck of the flask, as in Diagram 1.

5. Pour the contents of the beaker into the funnel.
   What does the liquid coming out of the funnel look like?
   What is left on the filter paper?
6. Take the funnel out of the flask. Pour the liquid from the flask into the evaporating basin.
7. Set up the apparatus as in diagram 2.
8. Heat the basin with a medium flame until there is only a very little liquid left. Remove the Bunsen burner and turn it off.
   What is left in the basin?

Additional work:

The following should only be done on the instructions of your teacher.

1. How would you try to show that soil contains some substances that are soluble in water?
2. How would you try to find out if tap water is pure?
3. Try to find out where salt comes from and how it is obtained on a large scale. Write a few sentences about it.

THE SCHOOLS COUNCIL INTEGRATED SCIENCE PROJECT

William C. Hall

THE intention of the Schools Council Integrated Science Project is to provide an integrated science course for the more able 13–16 year old pupil, which will lead to a double credit at 'O'-level. A timetable allocation of 6/7 periods per week will be required for the three years. There will be strong links with areas not normally included in science curricula, such as geography, economics and history, and sections of the work are devoted to studies in sociology, psychology, and geology. The technological applications and sociological implication of science will be emphasised throughout. The course will be an alternative to the separate sciences at 'O'-level and will be complimentary to the Nuffield Secondary Science Project[1] (which is intended for the less academic pupil).

A 'classical' approach to curriculum development has been adopted by the Project, and this is summarised:

1. Aims and objectives
2. Learning experiences
3. Assessment (and evaluation)
4. Revision of 1 and 2.

I. AIMS AND OBJECTIVES

As a result of following SCISP, it is hoped that the following aims will be achieved:

Knowledge

(1) To recall and to understand that information which would enable pupils to take A-level courses in biology, physics, chemistry or physical science, would enable them to follow a job in science and technology, would enable them to read popular scientific reporting and would enable them to pursue science as a hobby.

(2) To understand the importance of patterns to the scientist and to use these patterns in solving problems (both of a laboratory and of a household type).

(3) To understand the relationship of science to technical, social and economic development, and to be appreciative of the limitations of science.

(4) To be able to recognise scientific problems.

Attitudes

(1) To be honest in reporting scientific work

(2) To be concerned for the application of scientific knowledge for the good of the community

(3) To have an interest in science and technology and be willing to pursue this interest to higher levels

(4) To be willing to make some decisions on the balance of probability

(5) To be willing to search for patterns, to test for patterns, and to use the patterns in problem solving

(6) To be sceptical about suggested patterns

Skills

(1) To work independently and as part of a group

(2) To be able to use resources (e.g. books, aparatus) at their disposal

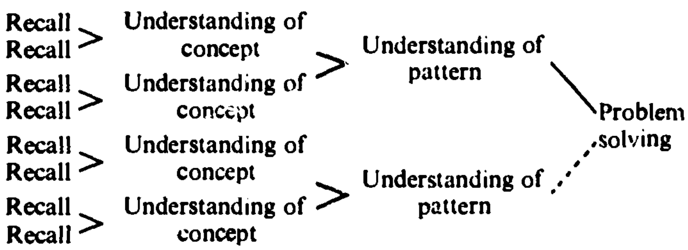
(3) To have the ability to organize and to formulate ideas in order to communicate to others, and as an aid to understanding, critical analysis, etc.

An interesting feature of the course, therefore, is that a positive attempt is being made to influence our pupils' attitudes.

The general aims are translated into specific objectives for each section of the sample scheme and then learning experiences devised for achievement of objectives.

II. Learning Experiences

A new approach to science teaching is being developed in SCISP which has been termed the "Patterns Approach". By a pattern we mean an important generalisation or explanation. Throughout the three years of the course pupils will be searching for patterns and then using these patterns to solve problems (both of a laboratory and everyday kind). This searching for and using patterns is the primary form of integration in SCISP. A careful build-up to problem-solving situations is believed to be essential and for this the following teaching framework has been adopted:



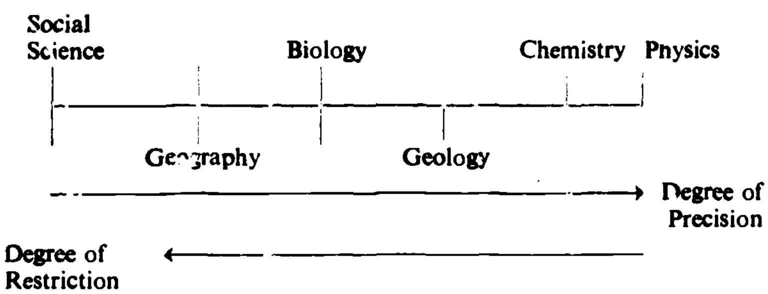
The framework is an adaptation of the last four types of learning in Gagné's *Conditions of Learning.*[2]

The content of the sample scheme which is being devised is based on three useful ideas of science: *building blocks* (ranging from the electron through cells and organisms to planets), *interactions* and *energy*. Integration of content (as distinct from approach) will be achieved in two main ways:

(*a*) building blocks are seen to vary in size and each is connected to the others; energy in biological and physical systems is the same

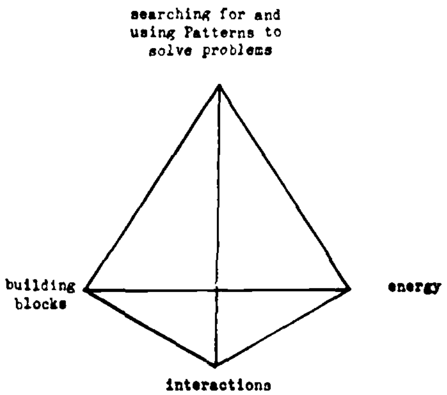
(*b*) biological examples can be taken to illustrate physical phenomena and vice versa.

There will be no forced integration of content. Indeed, in the final year, the differences in interactions of living and non-living systems will be emphasised. The following chart will illustrate what is in mind:



Variables in interactions in 'physical' systems are usually small in number, can often be isolated readily, and are almost always quantifiable. Interactions in 'biological' systems are usually more highly restricted (because of the presence of a large number of accompanying interactions), measuring instruments are blunt and there is a corresponding loss in precision.

The project model can be summarised as a three dimensional tetrahedron, content areas forming the base and the unifying approach as the apex:



III. ASSESSMENT

Assessment is an important and integral part of the course. Each section of the Teacher's Guides contains sample items for assessing whether objectives have been achieved, and a Working Party (under the chairmanship of Dr. Stephen Wiseman) is studying (among other things) the most appropriate ways of terminal assessment. An attempt will be made to assess *all* objectives (including non-cognitive) and it is hoped that achievement of attitude and skill objectives, as well as knowledge, will all form a part of G.C.E. 'O'-level certification. The Associated Examining Board will administer the examination.

Of course, a project such as this is a team effort involving Project staff, trials teachers, working parties and the Consultative Committee, and we are also fortunate to be accommodated in an annexe of the Centre for Science Education, Chelsea College of Science and Technology. Trials started in September 1971 and will end in July, 1973.

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W. C. HALL taught at King Edward VII School, Sheffield, and King Henry VIII School, Coventry. He then left teaching to become Science and Mathematics editor of a national educational publisher, but returned after 2½ years to be head of physical science at the Castle Vale Comprehensive School, Birmingham. After a year's secondment on the M.Sc. course in chemical education at the University of East Anglia, he was appointed Joint Organiser of the Integrated Science Project.

PHYSICAL SCIENCE AND EDUCATION

TECHNOLOGICAL STUDIES IN SCHOOL

I. T. James

IN higher and further education there has been a great increase in provision for the study of technology since the publication of the White Paper in 1956.[1] However at present technology still remains inferior in status to pure science. Information collected on behalf of the Robbins Committee[2] during the period 1961–3 has shown that in Britain less emphasis is given to technology and more to pure science than in the United States of America or any of our Western European neighbours. Indeed science not only attracts more students but also the quality of those attracted is superior. Another cause for dismay, and not only in Britain, was disclosed by the orbital flight of Yuri Gagarin in a Soviet Vostok satellite on 12th April, 1961; this was a vivid demonstration of rapid Russian technological development.

A disappointing feature of the educational scene at the beginning of the seventies is the decrease in number and standard of entrants to university courses in both pure science and technology, and the concomitant decline in the appeal of sciences to pupils in schools. There are several reasons for this decline, and one may be a mistaken view that school science is merely concerned with factual information which cannot be questioned. The truth, of course, is that no science claims infallibility, and that in every one doubts arise not only in research but in real life situations. Some teachers have started to ask if more experience of such situations ought to be given to sixth-formers, and whether the balance between imparting the fundamentals of pure science and introducing the creative work of applied science should be reconsidered. The problem is that of making children familiar with the role of technology in modern society.

Although it is normally easy to decide whether some particular activity or process or piece of knowledge falls within the field of technology, the term itself is not simple to define. Dictionaries offer, among others, the following definitions:

(*a*) the science of the industrial arts

(*b*) industrial science, systematic knowledge of the industrial arts
(*c*) applied science
(*d*) the use of science in making things
(*e*) the practice, description and terminology of any or all of the applied sciences which have commercial value.

In 1966, a report of the Committee on Manpower Resources for Science and Technology[3] stated that "in every technology the ultimate purpose is to exploit existing scientific or other knowledge for productive ends, whether or not all the processes involved in the technology are currently capable of scientific explanation." Thus the term technology has a variety of meanings according to the context, and consequently if a subject called technology is to be introduced into the school curriculum it will be essential to offer a definition appropriate to the scope of the work to be done in schools.

The Schools Council suggest that, as far as the school curriculum is concerned, technology may be defined as "the purposeful use of man's knowledge of materials, sources of energy and natural phenomena."[4] The needs of society will determine how this knowledge is applied in the service of man; society chooses certain objectives for which science and technology furnish the means. The enormous field of technology can be classified

(*a*) in terms of disciplines e.g. theory of heat engines
(*b*) in terms of impact on society e.g. automation.

The second type of classification is preferred by those educationists who favour a project approach.

Following a pilot study in 1966–7 on technology in schools, the Schools Council set up Project Technology in 1967 with headquarters at Loughborough College of Education. The objective was to prepare teaching materials for school use in the study of technology and also to seek assistance from those external sources best qualified to give it.[5] Technology in schools is a complicated business, for not only science and the traditional technical disciplines are concerned, but mathematics, economics and social studies as well. It could be the interdisciplinary subject par excellence.

In the past applied science and engineering have been generally excluded from the school curriculum, partly because they appeared to lack the prestige of pure science and partly because there were few graduate engineers on school staffs. Also there has commonly been doubt in university departments of engineering about the propriety of introducing the subject in schools. Some few schools, however, have had flourishing workshops for many years, and have encouraged their pupils to make full use of them, thus following the tradition established by Sanderson at Oundle. A creative approach through engineering projects often helps pupils to rediscover their initial interest in science which may otherwise wane during the final years of a traditional school course. Neither the selection of the project nor the planning and making of equipment are rapid processes, and it is often a good idea to have simple group investigations running alongside the projects while the latter are in their preparatory stage so that time is not wasted. Most pupils need considerable help in finding a project which offers interest but is not too difficult for some degree of success to be achieved. As soon as the project begins to progress the situation changes as if by magic, and the pupil's knowledge of his project far surpasses that of his supervisor.[6]

"The heart and soul of engineering lies in the fact that it is a creative vocation in which synthesis leads analysis and in which fundamental challenges are design challenges . . . It is a mistake to introduce into schools formal engineering courses and an engineering syllabus. From the viewpoint of discovering and recruiting the young engineer this is to put the cart before the horse. The essence of recruiting is to establish the motivation. The vocational motivation of the scientist is quite different from that of the technologist. The thrill of science is the thrill of detective work, of lifting the veil of nature, of illuminating the world. It is the thrill of successful analysis. The thrill of engineering technology is that of successful synthesis; the thrill of changing the world not of illuminating it; the thrill of conceiving and making things."[7]

Many of the schools which now offer work in technology have followed the lead of those few which for years have maintained their own workshops, and in consequence their projects are initiated in the technical department. This is not unexpected since the work in technology is in some instances simply an extension of the high quality craft experience which certain schools have offered to their pupils. They have been nurtured on design problems rather than on standard exercises. The growth of the electronics industry has made it possible to purchase in quantity many inexpensive components which can be used in various kinds of creative electrical projects. Opportunities for considerable development in this field appear likely. Using technical departments for the initiation of technological work has however a major drawback in the poor image which they commonly bear and which reduces their share of able pupils. Thus the development of work making progressively exacting intellectual demands is impeded. Those departments which have adopted a problem-solving approach are likely to be most successful in technological work.[8]

In other schools the technological investigations are based on the sciences. The teachers who favour the project approach see in it a means of maintaining a balance between knowledge on the one hand and its mode of acquisition and application on the other. Some regard the application of knowledge obtained as much more important than the knowledge itself. The range of projects is greater in schools where there is collaboration with technical departments, since the latter can often fabricate apparatus not otherwise available. Factors which may restrict the progress of science-based projects are the small time which can be given to them owing to the requirements of conventional examinations, the teachers' lack of appropriate technological experience and the difficulty of establishing co-operation between departments.[9]

The increased interest shown by pupils in social studies could lead at a later stage of education to a greater recognition of the social role in technology. The present inadequate control of pollution is an excellent example of the way in which the side effects of technological advance have been disregarded. Technology must show itself to be socially oriented and morally responsible, unlike pure science which is individual in outlook and amoral.

The rigid boundaries between subjects and the ever increasing content of courses of study are powerful obstacles to the interdepartmental co-operation which technological projects often demand. Forms of co-operation which might not be anticipated are between art and technical departments in problems of design, and between history and technical departments in the richly rewarding study of industrial archaeology.[10] Out-of-school activities are not impeded by the obstacles which exist within, and a "technical activities centre", meeting during the break for lunch or after school, provides facilities for individual or team inventiveness. The activities are normally directed by a member of staff or a senior boy; boys with adequate experience may work without close supervision. The motivation is aroused by interests derived from studies in school or by the infectious enthusiasm of individual senior members of the "technical activities centre".

In much of the thinking on the introduction of technology into the school curriculum all the emphasis is on the education of boys. One is tempted to ask whether the environment of girls is immune from technological advance. It is indeed true that relatively few girls look for a career in engineering when they finish full-time education. The prime reason seems to be the widespread and long-lived tradition that biology is the sole science suitable for girls. How many girls' schools have a workshop? And even in coeducational schools the situation is little better; the workshop is the preserve of the boys and the domestic science room that of the girls. It is good to observe that in some of the new junior high schools girls are being taught the elements of carpentry and boys do a little cooking and simple needlework. In schools, at present not many in number, where creative work in technology is being done by girls, the interests of the staff concerned are more significant than the nature of the facilities in the school. Experience in several schools indicates that girls show manual dexterity in electrical and electronic projects at least equal to that of boys. The projects which interest girls most are those having some connection with the home, and those in which they are able to see that the development of a new skill is essential for bringing the project to a satisfactory conclusion.[11] An example of the first type is an investigation of layout in the home based on elementary time and motion study. An example of the second is learning how to make simple joints in carpentry in order to make a stool for use in a kitchen. The interest of girls in technology is restricted by lack of workshops, courses in the use of tools and financial resources to provide them. Traditional views about the kind of careers girls ought to select are also a limiting factor.

In the upper part of the school the syllabuses of the external examinations determine what is taught to pupils of average and above average ability. Some examination boards now include technological subjects in their lists of options, as shown in the schedule below.

University of Cambridge Local Examinations Syndicate

- 'O' Level General Engineering Science
- 'A' Level Elements of Engineering Design; includes mechanical design and construction on a project basis
- 'A' Level Physics; bonus marks can be awarded for a report and oral examination on a project

Oxford Delegacy of Local Examinations

- 'A' Level Engineering: equal credit is given to engineering design, engineering science and course work

Northern Universities Joint Matriculation Board

- 'O' Level Engineering Science
- 'A' Level Engineering Science. Syllabus prepared by a panel composed of university lecturers in engineering and teachers in schools. Pass must be obtained in a project.

Associated Examining Board

- 'A' Level Engineering Science; credit given for practical work in experimental workshop practice
- 'A' Level Physics which may include a paper in Electronics
- 'A' Level Computer Science

An inspection of the schedule shows that formal courses in various aspects of engineering do exist in some schools. Supporters of such courses think that the Schools Council Project Technology is unfortunately named because the name may be taken to imply that real understanding of technology is gained only through project work. They emphasise that the formal course can give pupils in school a better introduction to the kind of studies they could expect to meet in the engineering courses of higher and further education. They also claim that the formal course provides a secure bridge between the pure sciences and the academic parts of craft subjects. One of the arguments advanced against the project approach is that it gives the pupils a number of disconnected pieces of information but fails to show them how these can be fitted together to yield a better understanding of the portion of the technological field to which they relate.

Whatever the nature of courses in the future one thing is certain; there will be more and more emphasis in the school curriculum on technology. Whether we regret it or not technology is an inescapable part of every pupil's future. Great Britain's lead in technological invention is being severely challenged. Since our natural resources are meagre it is essential that the maximum use be made of the inventiveness of our people. Such synthesising originality will be greatly stimulated if creative activities suited to the expanding abilities of children are pursued throughout their school life.

IVOR T. JAMES is an honours graduate in physics and mathematics of Cambridge and London Universities and taught for some years in a grammar school. During the war he was a Senior Technical Officer in one of the principal Ministry of Aircraft Production research establishments. From 1945 to 1948 he was the administrative officer of the Cavendish Laboratory in Cambridge. His interests include an appreciation of the organisational complexities of higher and technological institutions. When the former University College of Hull established the Institute of Education in 1948 he was appointed Secretary and is now the Deputy Director.

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PHYSICAL SCIENCE FOR GIRLS

M. Fowler

To frame a teaching scheme it is customary and proper to use the pupil's interest as a starting-point and to work out the details of subject matter and method with due regard to the children's capabilities and potential. Thus it seems right to consider the interests of adolescent girls and proceed to frame a programme of work which will foster the more desirable of these inclinations. To consider the scientific education of girls—and that narrowed down to the tighter aspects of the physical sciences—presupposes that a choice has already been made by or for these pupils. Justifying the inclusion of science in any child's education nowadays is virtually a superfluous task; society has seen the need for science education and it is rarely the individual teacher's decision that this subject should be part of the curriculum. Only the remnants of an earlier climate of opinion keep physical science out of the time-table of some girls' schools: an opinion which somehow regarded physical science a less feminine study than biology and resulted in a self-perpetuating shortage of competent women teachers of the subject.

Is the study of physics and chemistry within the scope and interest of adolescent girls? Or, to put another question, do the interests of adolescent girls lead to interesting and useful study within the curriculum subjects of physics and chemistry?

With girls of above average ability it is obvious that the answer to the first question is in the affirmative, although some science teachers would not be so positive in the case of the less able girl. The second question is more rewarding; put in this way, most science teachers would agree that we can trace from the pupil's interests fruitful courses of study.

In early adolescence girls' interests are centred on and conditioned by the physical and emotional changes which are taking place. That these changes generally occur at a different time and rate from those in boys is the greatest reason why the two sexes should be considered separately. Girls are interested in their appearance. They are preoccupied with dress, cosmetics and diet. They contemplate marriage at an earlier age than was common some years ago. From these interests can stem a wealth of worthwhile study, always remembering that the girl who will stay at school no longer than the statutory requirements compel her, is more concerned with things of the present, such as dress, cosmetics and diet, than with problems that may arise a few years ahead.

Thus the science teacher has a range of starting points. These will include a wide variety of cleaning and cosmetic preparation, natural and man-made fibres, dyes, plastics, foodstuffs and cookery, bodily movement and effort, all of which lead to interesting work in the physical sciences and within the scope of the pupils under discussion.

The girl entering a senior high school at thirteen will, it is hoped, have followed a general science course in her earlier years and the pupil who enters a high school at eleven will have a basic grounding in its lower forms. It is hoped that this elementary course will have given her a scientific vocabulary of terms and skills so that she is aware, through many practical and everyday examples, of the basic operations of solution, evaporation and the like, and will know in very simple terms something of the nature of matter, the meaning of physical and and chemical change including the concepts of force and energy. Such a basis lends itself to treatment compatible with the concrete-operational phase of development as described by Piaget, and the teaching will gradually be modified to include more generalisation and more of the applications of science. For children of average and below average intelligence (and, in my experience, this applies more to girls than to boys) these two aspects can sometimes clash. This may be because the science teacher who has come through the usual channels of training has studied at least one branch of science to some depth and has experienced its discipline through a theoretically-based approach to the subject. To attempt to encourage girls to make generalisations through some of the traditional lines of enquiry, especially in physics, is often unrewarding. The teacher has to look at newer, more immediate subject matter and guide the pupils towards feasible experimental projects which have some useful purpose.

Let us look at the prospect of teaching about synthetic fibres, for example, to girls who have little or no knowledge of organic chemistry. What does the average girl want or need to know? She asks about the fibre when spun, woven or knitted, if it will take a dye, if it stretches on washing, if it rots or dissolves in certain circumstances, if and in what manner it burns, if it sticks to or slips across other materials during sewing and wear, and how strong it is. She can collect examples, compare the breaking points of fibres, investigate the dye absorption and retention of pieces of white fabric. She will carry out simple electrostatics experiments to find out what kinds of dirt stick most readily to the samples. Then she can wash the soiled fabrics in waters from a variety of sources and containing different detergent or softening additives. Once such investigations into the properties of the fibres have been accomplished or are under way, then more theoretical aspects can be studied to give in simple terms the reasons for some of the results obtained. Constructing molecular models is appropriate at this point and the recognition of the similarity between some natural and man-made fibres gives the girls an inkling of how an organic chemist sets about his task. It is also necessary to make repeated reference back to the original theme to give point and coherence to the work. For example, experiments on the elasticity of fibres would be carried out in an attempt to compare the properties of fabrics in wear, and could be profitably rounded off by observing if one girl's skirt made of terylene keeps its shape better than a similar one made of wool.

Occasionally there will be opportunity to discuss the wider implications of scientific and technological change. In connection with the present example comments and questions will arise about the claims made by advertsiers and hence the value of the Trades Description Act. The ease of washing and drying the newer fabrics will help to make a girl realise that the role of housewife is not as physically demanding as in her grandmother's day. In another context will arise discussion about the increasing amount of litter and waste, especially plastics, or about air pollution. It is important that the average woman of the future has the opportunity to be informed about and discuss this kind of problem. The science class is a suitable venue for such discussion, following as it will upon the discoveries made by the girls themselves about such topics as the combustibility of plastics, their density and their solubility in common solvents.

Some of this work may not satisfy the traditionalist. However, it seems to me that if we give pupils the opportunity to make first-hand observations, encourage them to devise and criticise their own experiments (with discussion and guidance to avoid too many dead-ends and dangers), and then ask them to try to frame their own generalisations about everyday things, we are encouraging children to adopt a scientific attitude, and the facts acquired in the process are more likely to be of use and remembered than if we delve too deeply into the theoretical aspects of the subject.

Further, a girl may use her collected examples of fibres to compare their strengths, first by hanging weights on the end until the threads break. She will then look more critically at the experiment and possibly wonder if at the start of the investigation the lengths of each fibre should be the same, especially if she noted some stretching before breaking. She will begin to realise that the thickness of the fibre is an important factor and will possibly learn how to use an instrument to measure its diameter. She may question the use of the micrometer screw gauge to measure the thickness of soft threads, try to make some adjustments to her experiment and recognise that not every investigation has a definite result or can lead to further development.

One cannot assume that every pupil, once started on a line of enquiry, will ask the most useful questions. The teacher's role throughout will be much more than that of a mere imparter of information; discussion with groups or individuals will prompt new lines of study as the work proceeds. The teacher needs to explore the possibilities of the topic thoroughly beforehand so that he or she is prepared for how it may develop and be ready to present new but related aspects if interest flags. Work cards are, of course, useful provided that they give the girls scope to exercise their ability to make decisions and devise experiments at the right level. The mode of teaching should also encourage the girls to relate new knowledge to that gained in other situations; the most obvious link here is with domestic science.

It is still far more common for girls to have lessons in domestic science and needlework while the boys take perhaps woodwork, metalwork or technical drawing than for the boys and girls to follow joint courses in any of these subjects. Although the role of women in society is changing, much of the established pattern is likely to remain for some time into the future, but it is becoming imperative that boys should be able to manage properly some cooking and cleaning and that girls should be able to tackle simple household repairs and improvements. Not only do courses in, say, cookery for boys and woodwork for girls give each group a grasp of basic skills but they also impart some understanding of the problems and possibilities of each others' traditional fields of operation.

Physical science and domestic science come together at many points. For example, work on electricity will include study of common household appliances. The girls should examine cookers, refrigerators, washing machines, hair dryers and vacuum cleaners to compare wiring diagrams with the actual appliance, to study the cooling mechanism and the best positioning of foodstuffs in a refrigerator and to compare the structure and use of thermostats. Since it is not feasible for a group of girls doing science to investigate a cooker while it is in use by other pupils, and since subject syllabuses fashioned in isolation tend to fragment subject matter even more than it needs to be, the answer to this kind of problem is by some form of team teaching which will bring together the expertise of two or more specialists, in this case the teachers of science and domestic science.

Any effort to merge conventional school subjects helps to show pupils what a vast range is encompassed by human knowledge and sometimes is an encouragement to less able pupils who begin to see that one human being cannot be expert in everything.

Nowhere can the traditional subject limits be more easily blurred then between the physical and biological sciences. The boundaries of any topic are of course arbitrary and in teaching are often determined by quite mundane factors such as availability of equipment and reference books and not only by the extent of comprehension or interest of the pupils. Take the earlier example of man-made fibres. This subject could well be an off-shoot or progression from some work done in biology: obviously from a study of natural fibres, but possibly following the examination of common objects under the microscope. Also, the study of various washing agents will nowadays include those with a biological action which are well explained by analogy with the action of digestive enzymes in the alimentary canal. For those girls who are interested in science neither as another examination subject nor as a career prospect, general science can be a much more useful form than separated sciences for it is far less restricting in the choice of subject matter. The problem of finding suitable teaching staff who exhibit an all-round interest and competence in the various branches of science can be overcome by a close and organised liaison between science teachers which amounts to team teaching. This can prove a more satisfactory solution than half a school year of physical science and the other half biology.

My views on the teaching of physical science to girls among the crudely-labelled 'Newsom children', who will form a large proportion of the country's housewives and mothers in a few years' time, can be summarised as follows:

Since adolescent girls' interests are different from those of adolescent boys, they are worthy of special consideration, however the teaching situation is organised.

For girls of average and below average ability there is scope for a wide variety of practical investigations which are truly scientific and related to the girls' immediate interests and future needs.

We need to look into closer links between related subjects (including the relationships between different branches of science) and try to evolve new patterns of teaching so that these pupils may gain insight into different aspects of a wider whole.

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Let us now consider briefly the girls who early show some academic ability. It is likely that these girls will follow a curriculum closely parallel to that followed by boys; indeed in a mixed school boys and girls will take an identical course for some years. Little account is taken of sex differences and, in schools where too much attention is paid to neatness and layout in exercise books, the early superiority of girls in general is sometimes falsely assumed to continue. Tending to be conformist and conservative, most girls will follow a set pattern of work and not interest themselves in the wider implications unless there is outside stimulus to encourage this. As far as science is concerned the interests of adolescent boys give them more opportunity than girls to see science in action: a motorcycle is commonly regarded as an exciting product of science or technology whereas a loaf of bread is not.

When decisions are made about what subjects pupils will take at 'O' level the most able girls will follow a range of perhaps nine subjects identical with that taken by boys. In other cases, there will be some query about the sciences, and the usual solution is that the girls take biology while the boys take physical science. Over the past few years I have observed this pattern most markedly in questioning first year students at Kingston upon Hull College of Education, and in many cases the physical sciences were dropped out of the girls' timetables at the end of their third year in grammar school.

Girls who take physical science to 'A' level are often looking forward to a university course. Those who graduate find difficulty of acceptance on equal terms with men, a situation built up partly through tradition and prejudice, but sometimes also because a woman's academic attainment is not usually matched by the requisite physical skill or power. Of those who start upon a career for which her scientific education was a prerequisite, a high proportion marry and may join the ranks of the housebound women graduates "weeping at their sinks because they were wasting their qualifications and abilities in-home-making" as Catherine Avent[1] describes them. "These aroused little sympathy," she continued "*as there is no need for graduates to get married*". The italics are mine. I do not know if moral implications were in mind, but had I been writing that particular sentence the ending and the relation to its precursor would have been entirely different. As far as such complaints of women science graduates are concerned, they arouse little of my sympathy but for a different reason. The science education received to lead to a job should also have included sufficient of the right elements to make the career of home-maker a challenge and a joy. Such elements are the abilities to organise processes into a sequence of steps and stages, and to isolate factors relating a given effect to the correct cause. Further, the woman science graduates' general awareness should have led her to educate herself on matters outside science if she felt this had been lacking during her years of formal education. The present pattern of examinations does not, on the whole, lead to the inculcation of these good qualities, and the continuation of the kind of examination favouring convergent thinking, together with innate female conservatism are obstacles to their formation.

We should continue to seek far more flexible routes to qualification. It has been found, for example at Rosebery County School for Girls, Epsom,[2] that a large proportion of sixth form time can profitably be allocated to general studies without detriment to 'A' level results and university entry. The establishment of a university first year of general courses, as at Keele, is a manifestation of the belief that undergraduates should continue their education rather than undergo a training.

At the present time many women view their place in society with discontent. Those who are both intelligent and educated should have less quarrel with society than others, especially those whose education was not commensurate with their potential. To be writing on the science education of girls at this time is particularly piquant, for physical science was the subject most avoided or neglected by women even after education became an accepted right of girls as well as boys. Also scientific advance has been the cause of much of the malaise: because of improved technology women are not the drudges they were and have more time to occupy outside the traditional role of housewife.

When we are concerned in the teaching of physical science to girls, whatever their ability, I suggest that we endeavour to look forward to their lives after formal education is over and that we view the subject, not in isolation, but as one part of the whole educative process. It seems to me that any course although based on the pupils' interests, should not be bounded by them. In the study of science we should recognise that with adolescents the differences between the sexes' interests, aptitudes and abilities are complementary.

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CAN A STUDY OF SCIENCE EDUCATE?

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ATTEMPTS which have been made in the last decade or so to bring the teaching of science in schools more up to date, have brought into prominence a problem which has been with us, in fact, since modern science began. It is one which affects the whole field of scientific studies, though it occurs perhaps most acutely in the physical sciences. It arises from the fact that the observation of the phenomena of nature can only be carried out in the light of a theory to direct attention to the important points. It is extremely doubtful whether undirected observation ever played a significant role even in the biological sciences, and certainly in the physical sciences 'stamp collecting' is of little value—as well as being practically very difficult indeed to do. Furthermore modern scientific studies have to be based upon modern theories, and these operate in terms of numerous 'inferred entities' such as atoms, electrons, the whole range of subatomic particles together with electromagnetic radiation, the existence of which lies beyond the reach of the senses. The problem which presents itself immediately is, what is to be the attitude of the pupil when faced with these very remarkable and recondite conceptions and assumptions, which the theories contain? How do, how in fact can, scientists know about the structure of matter in such remarkable detail? What credence is to be accorded their views? Should the pupil attempt to adopt a critical attitude to theory, and if so on what grounds can he base his criticism? The problem is not made any easier by the superficial familiarity with some of the theoretical ideas which children acquire at an early age through reading, listening to broadcasting and watching television. Should they therefore, on the other hand, accept the theories on trust? If they do accept them on trust what conceivable intellectual interest can the study have and how can it justify a place of importance in the curriculum? This problem is of the utmost importance in the teaching of science, and there is little doubt, in my mind, that failure to solve it is among the reasons for the lack of attraction which scientific studies hold for many of the abler pupils. The judgment of the individual is so overwhelmed by the formidable structure of theory which confronts anyone wishing to take an intelligent interest in science.

The educational value of any study depends very much upon how far it can develop powers of judgment in the pupil. A literary education seeks to develop the pupil's literary judgment, and an historical education his historical judgment. Does a scientific education develop powers of scientific judgment? Some of those who maintain their studies to the end of the university course no doubt do so in some measure, but that measure of judgment which most school science courses create, even assessed very sympathetically, could not often be put at more than embryonic. No doubt the teaching of history and languages often fails to achieve its full potential in this respect also, but there can be little doubt that science courses, by and large, lag far behind.

School science, and indeed much of the science taught at universities, tends to be based only upon the well established theories of science, which it is very difficult for anybody to question, and the questioning, if attempted at all, would need a very careful experimentation if it is to produce anything worthy of consideration. Is this as it should be? There was a time in British schools when this particular difficulty was realised by teachers of science, and study used to be included of theories, now abandoned, such as those of caloric and phlogiston, as illustrations of the scientific method. The revival of such studies today, lacking as they would be in contemporary significance, is hardly to be advocated. At the same time the basic problem of how to develop a scientific judgment and a critical attitude remains unsolved.

A few opportunities which do occur are often allowed to slip. I used often to hear a physics lesson given to sixth-formers in which it was 'proved' that the angle of projection for a projectile to attain maximum range on a horizontal plane is 45°. When asked whether they considered such a demonstration convincing, pupils hardly ever knew how to answer. Then after glancing over the mathematics (it is little more than a couple of lines long) and finding no flaw in it, they usually professed themselves satisfied. But why then is this angle hardly ever used in practice (e.g. the long jump, putting the shot, the javelin, discus or in golf)? The reasons differ in the different cases, but in each case it is the assumptions which were used as a basis for the mathematics which were not applicable. The pedagogical failure here is that the pupils had had no experience in criticising the applicability of a piece of mathematics. It is true that the mathematical reasoning needs to be checked stage by stage, for one's own personal satisfaction, but the examination is rarely rewarded by the discovery of an error. On the other hand scrutiny of the initial assumptions can often reveal that the conditions are not met in practice.

Scientific theories vary from the almost purely hypothetical to those which have been most extensively confirmed by observation. Some of the latter, such for example as our present picture of the solar system, would be almost impossible to jettison, however critical we might wish to be. The pedagogical question is how the school-boy is to be given sufficient grounds for him to form his own judgment and distinguish between the various theories with which he will be confronted. Clearly, if the problem is to be solved the pupil must meet a range of scientific theory and the teacher must not feel himself to be concerned with 'putting across' a particular theoretical point of view.

As an example of a theory which originated in scientific observation but which we would unhesitatingly reject, and which might deserve a passing reference in a school study we might take the case of astrology. It is true that we would not now classify it as a science at all, but this is merely the judgment which we wish to discuss. Astrology remained respectable right down to the time of Kepler at least, and it probably arose as a result of the same observations which gave rise to its sister science of astronomy. The stars always rise in the same place on the horizon at any one position on the earth's surface, but at different times of the day as the year progresses. The risings of the various constellations were used in ancient times to mark out the seasons. Hipparchus used them, for example, when he discovered the precession of the equinoxes. In ancient Egypt or Mesopotamia, corn would be sown when a certain constellation rose at sunset. The Nile would flood when another constellation did the same. It is but a short step from this to assert that the constellations exert direct influence upon affairs on the earth. The linking of the tides with the phases of the moon would confirm this inference. Yet now we would reject it. It is interesting to discuss why. Perhaps we demand that some understandable mechanism should underlie our theories. If we do, are we sure that we always get it in the theories of modern physics?

However, when we have made the most of such examples as these which we can think of, it has to be admitted that they are not easy to find and that, at best, they can furnish only a part of the solution. We have rejected phlogiston on grounds of relevance: astrology is by no means so remote, as a glance at a popular newspaper will readily confirm, and there are large areas of the globe where it is held in undoubted esteem. The newspapers of the East, with their advertisements requiring the horoscopes of prospective spouses, can be an eye-opener. Astrology and some of the more speculative theories of cosmology can be made use of, but what is really required is some study, at a more or less adult level, of the whole nature of scientific argument, to which these passing references can lead.

Universities have initiated courses on the History and Philosophy of Science, having such an aim in view. In so far as it is possible to tell in the matter of university courses (few people are familiar with more than one at the most), these studies appear to be dominated by the history, leaving the philosophical side to mature on its own, with the history as a basis. For school purposes this is not very satisfactory for the same reason that led us to drop phlogiston. Some pupils can be interested in the history of science for its own sake, but many would wish to see a more obvious relevance to the views of the present day. The history of science has, indeed, relevance to the present day, but its relevance is philosophical, and in schools, in my opinion, it would be better to go directly to the philosophy itself.

Not so long ago philosophy was regarded as an off-shoot of the classics, and its study was approached via the writings of the ancients. Today there can hardly be a better approach to the subject than via the sciences, since so much of it concerns the theory of knowledge, to which science is very relevant. Indeed philosophy can hardly be properly appreciated at all except against a background of scientific knowledge.

The problems to be discussed are these. All that we are aware of is the result of the impressions of the senses. Deprive us of sight, hearing and the senses of touch, taste and smell, and we would be completely isolated, aware of nothing except that which might be derived from memory of previous sense impressions. The human race, and no doubt the higher animals also, have evolved in such a way that these sense impressions are interpreted as arising from the impact upon us of a world external to ourselves. What is the justification for this jump? There are a number of similar jumps which we make and which are equally difficult to justify. Granting the existence of an external world, how from the observed behaviour of others do we pass to the existence of other minds? Again granting the existence of common objects, how do we pass to the inferred entities of science to which the senses are unresponsive? How from a knowledge limited to the present do we pass to a knowledge of the past?

In the physical sciences it is the passage from common objects to the inferred entities transcending the senses, in which we are mainly interested, but this problem cannot be solved in isolation from the others. In philosophy the problem of the world external to the senses has been the centre of interest around which the others have been grouped. It would be well to start by looking at this in the first place. When we turn our gaze to the heavens we are aware of a visual field punctuated by numerous points of light. It has been for only a comparatively short time that we have been accustomed to interpret these as originating in very distant bodies similar to the sun. We are also aware in the visual field of the presence of larger and brighter patches of light. For a somewhat longer time we have been accustomed to interpret these as emanating from members of the solar system. It is to George Berkeley (1685–1753), Bishop of Cloyne, Ireland, 1734,[1] that we are indebted for pointing out that the existence of the external world is a similar interpretation of sense impressions. Science assumes that the justification for this interpretation has been established, Science adopts the point of view described by Locke,[2] but after Berkeley, Locke's reasoning is no longer tenable. The same applies to scientific reasoning. Berkeley had a solution to his problem but we can hardly be satisfied with it. (It was that the furniture of the earth was ideas in the mind of God). We are therefore faced with a gap in our chain of reasoning. We need, further, to take account of Hume's[3] critique of cause and effect and its implication that it is impossible to apply logical principles to natural phenomena. Though the relevance of all this questioning to the scientific method is obvious enough, through all this discussion it will need to be kept in front of the student.

A part of the discussion would naturally be a consideration of some of the attempts which have been made at a refutation of these views. Dr. Johnson[4] refuted them with alacrity thus—by "striking his foot with mighty force against a large stone, until he rebounded from it". It is not difficult to see that Berkeley and Hume cannot be refuted by kicking a stone, but there have been serious schools of philosophy based upon the primacy of common sense. The gist of the writings of G. E. Moore[5]—the philosopher of common sense—and in particular his "proof of an external world" deserve study, even though it is perhaps difficult to see what advance he actually made upon Dr. Johnson. He held up his two hands instead of kicking a stone. G. E. Moore may be looked upon as the founder of a whole school of philosophy derivative from his point of view. He was followed by the linguistic analysts who gave primacy to common language and attributed philosophical difficulties to the misuse of language. By their analyses they attempted to show that philosophical 'worries' can be dissipated.

What Moore seems, in fact, to be saying is this. There is nothing of which we can be more certain than we can be of the world of common sense. It is therefore appropriate that philosophers should make this the basis of their philosophy. Bertrand Russell[6] adopted a similar attitude, but the world of which he felt most certain, and which he made the basis of his philosophy, was the world of physics, with all its inferred entities built in. The drawback to all these philosophical views is that within the language of each school it becomes impossible to question the basic premises. Thus the linguistic analysts are unable to question the validity of ordinary language, G. E. Moore cannot question that of common sense and Bertrand Russell physics. For the purpose of formulating a critique of the theories of physics, therefore, none of these systems can be of much value.

The student of elementary science may feel a study of philosophy frustrating. Nonetheless it is very salutary. In his scientific studies he assumes the validity of common sense, the reality of the external world and the operation of causal sequences within it. Unless the objections of Berkeley and Hume can be met, these assumptions will remain as a flaw in any subsequent scientific argument. The questions cannot just be forgotten.

Another avenue of attack on the problems which the student should consider is that provided by Bayes' theorem.[7] For a time it was felt that it might provide the required answer, although it seems likely that Bayes himself never thought so. According to Bayes' theorem, as deductions from a theory are confirmed by observation, the probability of the theory being true is multiplied by a factor greater than one, so that after several deductions have been confirmed, the final probability may approach unity. The more difficult it is to account for a deduction in other ways, the greater the multiplying factor becomes. We thus need to know all the alternative ways of accounting for it, and in addition the theory needs to have a finite prior probability of being true before the process of testing begins, since if the initial probability was zero no amount of multiplication could make it any different. Neither of these conditions can be met in practice, and in spite of the fact that there are undoubtedly some situations in which Bayes' theorem can be applied, as a logical basis for the general process of scientific induction, the theorem cannot succeed.

We are thus driven elsewhere in our search for a basis for the scientific method. A book which made an important contribution to the subject was the *Logik der Forschung* of Karl Popper,[8] written in 1934. An English translation was published in 1959. Popper emphasised the fact that scientific theories can never be verified. They can only be falsified. He sought to replace the invalid argument "Given that if A is true B follows, and also that B is found to be the case, the conclusion is that A must be true" by the valid one "Given that if A is true B follows and also that B is found *not* to be the case, therefore A is false". It is by attempting to falsify theory that science advances. In order to be falsifiable the theory must 'stick its neck out' and make statements which are beyond what can be justified by existing evidence. In many ways Popper's views were the direct antithesis of what had been held before and epitomised in Bridgman's[9] operational analysis, according to which physical theories should be stripped of every element which cannot be verified experimentally. Such a theory, according to Popper, would then be unfalsifiable, and incidentally useless as an instrument for scientific advance.

What in fact Bridgman and Popper brought to light was that scientific theories have a dual role to play. Previously they had been thought of as summaries of knowledge. To be valid as a summary of knowledge they must not contain within them more than has been ascertained so far. As a tool for research the exact opposite is required. The theory must contain suggestions which are uncertain and open to test. If we are interested in increasing the sum total of scientific knowledge we shall esteem most highly theories which are speculative. On the other hand, if we wish to assess the validity of the views which the theories contain, we shall wish to examine the basis on which they rest, and it will be as a summary of knowledge that we shall attempt to evaluate them.

It is with regard to the latter aspect that Wittgenstein[10] has a claim to consideration. He wrote two books—the *Tractatus Logico-philosophicus* and *Philosophical Investigations*—and there are also some published notes known as the Blue and the Brown Books. However, as reading matter for use in schools I would say that they are almost hopeless. In order to get his students to think things out for themselves, Wittgenstein appears to have adopted the policy of wrapping his ideas up in long series of examples, and it often becomes very difficult, from a reading of his writings, to see what he is driving at. The ideas which we require for our present purpose are simple. In the *Tractatus* he developed the idea that in scientific theories 'we make to ourselves pictures of facts'. This view he abandoned in his *Investigations*, presumably because, along with Locke, he was without any method for ascertaining what the facts could be, of which we are to make pictures. The solution he then adopted he entitled 'seeing as', to which long passages in the *Investigations* are devoted. We see heat as a fluid flowing through a conductor or as the kinetic energy of molecules; we see a gas as a crowd of moving molecules and so on.

This seems to me to be as good a picture of the scientific method as we are likely to obtain. It may suffice for our purpose if we know, for example, that a gas behaves *as if* it were composed of swiftly moving particles. For some purposes hard billiard-ball-like particles suffice; for other purposes a more elaborate model is required. We must know not only the picture but also the context in which it is valid. Whether or not the picture describes some external reality it is never possible to say. It is possible so to mould our picture to fit our experience that we become convinced that it must correspond to a reality underlying the observable phenomena.This, however, can never be shown to be the case. Such questions should be excluded from the province of science. They belong to metaphysics, not to physics.

This view of science enables us to understand very easily a point which is otherwise difficult. When two theories are available to explain a given phenomenon, we choose the simpler. Why? The answer which many physicists would give would be "Because the world is, in some deep sense, simple". This is nonsense. The world is as we find it, and it is far from simple. It is most certainly not the simplest universe which can be conceived. One, for example, at the absolute zero of temperature would be simpler than that which we know; one without electromagnetic radiation would be the same and so would one which was completely static, without gravitational forces and so on. Admitting finer grades the number of worlds simpler than the one we know is infinite. However, if all that science is doing is to make pictures for us to help us think about our experience, the situation becomes clear. If two such pictures are available we would be extremely foolish to adopt a more complicated one when a simpler one will do. All that we would succeed in doing would be to make our thinking that much more difficult.

In what I have written above I have outlined in the broadest possible terms the sort of study which I believe science students in the sixth forms of schools would find profitable. To start with they may feel that the investigation of so many blind alleys to be unfamiliar and unattractive. This, however, should be capable of being surmounted. In philosophy, in marked contrast to what we find in the sciences, we are presented with many different attempts to find a solution to a problem, none of which is entirely satisfactory. Unless the strengths and weaknesses of the most important of these are understood, we cannot but fail to appreciate the dimensions of the problem. However, the very uncertainty and difficulty could provide a valuable antidote to the dogmatism of much of science teaching, lend importance to the judgment of the individual, and help to restore science to a place among the accepted vehicles for education, from which, because of its complexity and apparent infallibility, it has tended to slip. A not unimportant further consideration is that such a study might allow science students to join those of other disciplines, who are also interested in these and other aspects of philosophy.

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compiled by JOHN F. HOOTON, Assistant Librarian in the University of Hull Institute of Education.

NOTE *With a few exceptions this bibliography does not include school textbooks or books on specific scientific topics unless they are significant from the point of view of teaching method.*

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