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Since 1959 there have been over thirty articles in the *Bulletin* on educational topics. This testifies both to a dissatisfaction with existing conditions and to the interest shown in physics education by physicists whether or not directly concerned with teaching. In January 1962, Mr. Norman Clarke wrote[1] summarizing the position as follows: 'What seems to be needed in this country is a vigorous policy designed to produce a course, as distinct from a syllabus, which will be a suitable general education in physics for all children.' He enlarged also on the need for aids of various kinds to assist teachers in their work. Before 1962 was out, he was to see the start made on the Nuffield Foundation's science teaching project which was to meet the needs he listed. Development work on the O-level courses has been continuing since then, the final trials are now in progress, and the material will be generally available for use on publication in April 1966. It seems appropriate that some account should now be given of the work that is going on and what it is hoped the Nuffield physics program will achieve.

Early history

In England the first moves towards revision were made by the science teachers themselves. In 1957 the Association for Science Education (the Science Masters' Association, as it was then, working with the Association for Women Science Teachers), was encouraged to look critically at syllabuses in physics, chemistry and biology and to make recommendations for the future. There was increasing dissatisfaction with existing syllabuses: in physics there was little awareness of any developments since 1900, the syllabuses were heavily overloaded and there was an emphasis on factual knowledge, perhaps mainly because it was easily examined. The first publication was the *Policy Statement*[2] of the A.S.E.'s Science and Education Committee, followed shortly by detailed syllabuses in physics, chemistry and biology prepared by special panels. The work of the physics panel was discussed in the *Bulletin* by Mr. E. W. Tapper.[3] It is perhaps a measure of the success of those syllabuses that most examining bodies have now modified their O-level and A-level syllabuses on the lines advocated by the A.S.E.

The new physics syllabuses accepted the need to be relevant to the second half of the twentieth century and included some 'modern' physics (though this merely means some physics since 1895). This presented considerable difficulties in teaching and the A.S.E. set up a special committee to work on it and a report was prepared.[4] The problem in the teaching of modern physics lay in the ease with which the subject could be taught by assertion and the relative difficulty in making it a satisfactory educational exercise in which the pupils could see the evidence for themselves and exercise their own judgment. Herein lies the trouble with so much science teaching in the past: too often it became a matter of dogmatic assertion by the teacher and has lacked the intellectual exercise of other disciplines; too seldom has it been a subject in which the pupil has to think and to think criticially, though in fairness to the teacher this has often been because of the strait-jacket of the examinations. The results of pilot-scheme trials conducted under the combined auspices of the A.S.E. and the Secondary Schools Examinations Council have shown that some twentieth century physics can be taught in schools and taught well. Already most Examining Boards have included much of the material in their new syllabuses.

Other winds of change

At the same time that the Science Masters' Association and the Association of Women Science Teachers were doing their work on syllabus reform, other winds had begun to blow across this country. The strongest wind of change came from the United States of America where the Physical Science Study Committee was developing its secondary school course. Their program has already been discussed in detail[5] and need not be described here. Perhaps, however, the greatest tribute that can be paid to the late Professor F. L. Friedman, to Professor J. R. Zacharias and to the remarkable team from M.I.T. and elsewhere who prepared this school program is not the wide use of it in the United States, nor the number of foreign countries that have adopted it, but the influence it has had throughout the whole world stimulating reform far beyond those countries which are using the actual program.

The P.S.S.C. scheme has commanded respect in the British Isles and it has certainly influenced our thinking, but it is never likely to be widely used here. A course of a relatively sophisticated nature intended to last a year (or a year and a half) with children aged 16 or 17 just does not fit our well-established tradition of science teaching extending for children from the age of 11 to 16 or 18. Furthermore, the American scheme was developed for use in American high schools where the mathematical background is much more restrictive than in our own tradition.

In addition to the influence from America there was also an increasing awareness in Britain of progress in other countries. There was the example of West Germany which had set aside 18 million Deutschmarks (just under £2 000 000) for apparatus for the teaching of modern physics in secondary schools, which accounted for the wealth of first class demonstration apparatus to be found in almost every German *gymnasium*. There was an increasing awareness of what was being done in the U.S.S.R.,[6] where it was claimed that they had enough teachers of physics, but that they would never have enough good teachers. Provision was therefore made of the wherewithal to enable the indifferent teacher to achieve a standard. The teacher not only had a syllabus of the topics to be taught, but he was given lists of demonstrations and experiments to be done by the pupils themselves, he was provided with all the apparatus necessary and with all sorts of visual aids including films to relate the physics to the outside world. This of course was intended to set a minimum standard and there was scope for the teacher developing additional ideas of his own. It was exactly aids of this kind for which Mr. Norman Clarke was expressing the need in his article[1] quoted at the beginning of this paper.

Besides examples set by individual countries, there were also great winds of change coming from international gatherings. O.E.C.D. set up an international committee to assess the needs and the report[7] issued in 1961 laid down principles for reform. Following the recommendations, O.E.C.D. arranged a series of conferences in Malvern, in Milan, in Uppsala and in Paris to make detailed suggestions. Unesco was already making a major contribution to reform and under their auspices and that of the International Union of Pure and Applied Physics, two major conferences were arranged in Paris and in Rio de Janeiro, the major part of both of which were devoted to physics education in schools, thereby testifying to the world wide interest in reform in physics education.

Finally a conference on science teaching in Colombo in December 1963, organized by the Commonwealth Education Liaison Committee showed how much activity there was in different parts of the Commonwealth.[8]

The need for the Nuffield program

With so much international activity, and with so much work done by the A.S.E. in this country, why was there a need for the Nuffield program?

In November 1961, Mr. J. W. Warren wrote:[9] 'A radical reform of physics education is urgently required. Although reduction of excess material is vital, little else will be achieved just by introducing new syllabuses since the same ideas will inevitably be taught. What is required is a critical attitude. . . . ' Earlier Mr. Clarke was writing[10]: 'Great importance must obviously be attached to the subject matter of a course and the way in which it is developed as a logical whole. Of even greater importance is the way in which the teacher handles the subject matter.'

There is necessarily a great deal of difference between the publication of a syllabus (which often amounts to little more than an examination syllabus) and a complete teaching program. It was widely accepted that there was much more that needed doing than producing syllabuses: what really mattered was the method by which the subject was taught. What had to be done in detail was beyond the limited resources of the A.S.E and it was here that the Nuffield Foundation has come to the rescue. It decided in 1962 to produce complete teaching programs as had been done in the United States for American schools by P.S.S.C., but suitable for the English needs.

Consultative committees were set up for physics, chemistry and biology under the chairmanships of Professor Sir Nevill Mott, Professor R. S. Nyholm and Professor M. M Swann respectively. In the first instance £250 000 was set aside to enable teams to be seconded from their teaching to work full time on the physics, chemistry and biology programs. The trustees of the Nuffield Foundation have now increased this sum to £430 000. In addition it is also committed to a further £250 000 for the publication of over 120 volumes for the three programs, for which there is likely to be a first printing of close on three million books, though this sum should eventually be returned to the Foundation in revenues from sales.

The Nuffield projects

The Foundation decided to concentrate first on five-year courses in physics, in chemistry and in biology, suitable for children from the age of 11 to 16 in grammar schools (and possibly the top streams in secondary modern schools), corresponding to the O-level stage. Development work on this program, which began in 1962, will be completed in the summer of 1965 and published in April 1966. It will be freely available for use by schools from September 1966.

There were a number of good reasons why the 11 to 16 age group was chosen for the first task of the project. The *Progress Report*[11] states, 'Because one important aim in reforming science teaching was a wish to see that science should form a part of all liberal education, the first four or five years of secondary education were obviously crucial. But this is also the stage in the educational system in which reform may be expected to have particularly far-reaching consequences, for this is when non-specialists make acquaintance with science, and when future specialists acquire the foundations of their scientific disciplines.'

In January 1964, work also started on a primary science project. Preliminary work has furthermore begun on A-level work for the 16 to 18 age group and the main project work on this will begin in 1965. The Foundation has also started preparatory work on science courses for what is now known as the Newsom group (the children of average and less than average ability): this work has lagged behind, not because it was considered less important, but as the O-level courses might well give useful guidance it seemed wiser to complete them first. Consideration is also being given to the feasibility of a combined science course for the age group 11 to 13 as this is likely to be another need within the framework of O-level work in grammar schools.

Donald McGill, an inspector in the Scottish Education Department, was appointed the Organizer of the Nuffield physics project when it started in 1962. He laid the foundations for the program and started the project on its way. On his untimely death early in 1963, Professor Eric Rogers, the English physicist now Professor of Physics at Princeton University, was appointed Organizer to continue the work with the writer as Associate Organizer. On Professor Roger's partial return to Princeton in September 1964, Mr. E. J. Wenham of the City of Worcester Training College joined John Lewis as another Associate Organizer with Mr. D.W. Harding of St. Paul's College, Cheltenham, as Assistant Organizer.

It was considered essential that before the program was made available it should be thoroughly tested in schools. For this reason all the material, developed by teachers for teachers, is now being tried out under classroom conditions and modified in the light of this practical experience. From 1963 to 1964, there were 16 schools in the trials, this was extended for 1964 to 1965 to over 50 schools involving about a hundred physics teachers in regular weekly feedback. Schools of all kinds (boys', girls', and mixed, grammar schools, modern schools, comprehensive schools, direct grant schools and a few independent schools) have all been involved. It is hoped that the final material will form a co-ordinated whole to be used by individual teachers as they think best. Those involved hope, and the present trials encourage them to believe, that there will be very many who will follow the new approach. The Nuffield science projects are doing a piece of research work on a scale never before attempted in this country: the extent to which the work is ultimately used will depend solely upon its merits.

Principles of the program

It is a relatively easy task to find fault with traditional school work in physics. In developing the new program some basic principles had to be very carefully thought out.

In 1960, Mr. Clarke wrote[10]: 'The presentation of any school subject should be devised in such a way that a rounded, consistent and realistic course of a general educational nature should be offered. Children who leave school at the age of sixteen should not automatically be restricted only to a partial course devised with the needs of a specialist, who will continue for another two or more years at school, primarily in mind' and again later: 'There are two main criticisms of the usual presentation of physics in schools. Firstly it is dull and makes no conscious attempt to build upon the natural advantage which the science teacher has in the common curiosity of children . . . Secondly . . . it is circumscribed and incomplete. It fails, and indeed could hardly be said to attempt, to give children a broad picture of what modern science is about and the way in which scientists think.'

Mr. W. R. Elliott suggested[12] that the main ideas introduced into a child's education should be few, but sufficiently important that they may be thrown into every combination possible so that the child may make them his own and understand their application in the present circumstances of his actual life. He quoted A. N. Whitehead condemning giving pupils scraps of information and teaching small parts of a large number of subjects, which encourages the passive reception of disconnected ideas, not illuminated with any vitality, and ends up by producing the merely well-informed man who is 'the most useless bore on God's earth'.

Quoting Mr. C. B. Spurgin:[13] 'If there is one common complaint by science faculties and examiners about science students . . . it is that they know but do not understand. The emphasis in all changes must be on the improvement of the degree of understanding by the pupils.' Finally Dr. R. A. R. Tricker wrote:[14] 'It is essential to lay a foundation of simple empirical studies in which pupils become familiar with the more striking phenomena of nature. Let this study be permeated, as far as we can arrange it, by a spirit of inquiry.'

What is the implication of these suggestions? (*a*) A physics program should be complete in itself. (*b*) It should build on the natural curiosity of the children. (*c*) It should be relevant to the world outside the classroom. (*d*) It should give a broad picture of what modern science is about and the way in which scientists think. (*e*) It should not contain too much material, but a few important ideas which the pupil can make his own. (*f*) It should strive for understanding. (*g*) It should foster a spirit of inquiry.

These are precisely the principles which have guided the development of the Nuffield physics program.

Teaching physics for understanding

Teaching for understanding is a phrase used much in the Nuffield program. This should not be thought to imply that there has not been teaching for understanding in the past: of course there have been many good and devoted teachers who have striven for it and achieved it. But for a very high proportion of children, physics has been the mere acquisition of factual knowledge, of definitions to be learnt by heart, of formulae to be remembered and of a series of mechanical rules to derive an answer, too often appearing irrelevant to the pupil's interests. There was far too much dependence on dogmatic assertion, whether by the teacher or the textbook, far too little opportunity to get the pupils to think for themselves, to look for evidence and to use their judgment.

The aim in the projects has been 'science for all', science as a part of general education. It has been the education of the future citizen that has been considered, the future bank manager, the future lawyer, the future nurse, the mothers and fathers of future generations. It is a rather painful and certainly salutary experience to ask one's bank manager whether he did any physics at school and how much he remembers. Traditional courses, and traditional examinations often failed to give understanding or any indication of what lay behind the detailed facts. Although the 11 to 16 year-old course has aimed at general education, it is believed that at the same time this program for the future citizen is also a very good foundation for the future scientist and engineer. The evidence from the universities is that a sound knowledge of what science is about with an understanding of certain basic principles and topics is a better foundation for the future scientist and engineer than a vast number of ill-digested facts, improperly understood, and a string of formulae into which substitution can give a 'correct' answer without understanding the principles involved.

The old proverb 'Hear and forget, see and remember, do and understand' is perhaps the clue to how this understanding is to be achieved. Demonstration is considered better than talk and chalk, but in the Nuffield program it is hoped to get the boy or girl personally involved and by 'doing science', instead of hearing about it, to come to understanding. There is a great wealth of new, simple apparatus which enables pupils to gain experience, to make their own investigations and to foster the spirit of inquiry. There is far less talk by the teacher, far less giving the 'correct' answer. Questions from pupils are much more often met by further questions to help them find the answer for themselves.

Content of the course

It cannot be too strongly stressed that in all the Nuffield projects there is a conviction that a syllabus, in the sense of a bare list of topics, should never be considered in isolation from the method of teaching. The aim is to develop understanding and this has led to fewer topics being taught than has been customary in recent years. What is included does attempt to form a connected program, in which something learnt in one place proves useful somewhere else, and something discovered later throws light back on something worked with earlier. In this way it is hoped that pupils will come to feel that physics makes sense, that science is not just a series of statements to be learnt by heart, facts to be accepted for reproduction in an examination or a series of formulae, but a unified fabric of knowledge, linked together and certainly making sense.

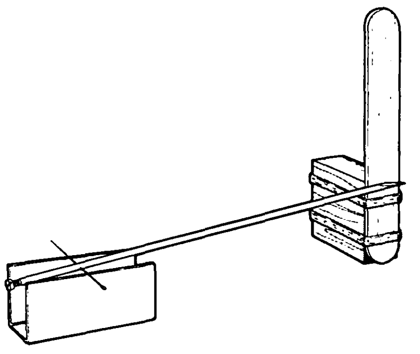
In the past a young boy often came to science in his school full of enthusiasm for this new subject, which he associated with atoms and electrons, with rockets and satellites, with radioactivity and so on, and then had this enthusiasm gradually killed by making him find the focal length of a lens by five or six different methods, learn by heart a whole series of definitions or measure the specific heat of copper, brass, zinc, aluminium or lead, merely because one of these may 'come up' in the O-level examination. In the Nuffield program we believe we have a duty to meet the pupil's interest and there has been no hesitation in including a number of 'modern' topics.

Because it was considered essential that the program should be a connected one, it was necessary in deciding on the content to start with the end point. It was considered important that in Year V there should be some feeling for the relationship between experiment and theory, and also some understanding of the part 'models' play in scientific thought, how a model is only significant as long as it is useful and how it is only a model. It was also considered desirable to include something on the uncertainties in science to avoid the impression that 'science knows all the answers'.

To show the relationship between experiment and the development of successful theory, some planetary astronomy is included in Year V. This required work earlier in Year V on motion in a circle, including an experimental derivation of v^2/R. This necessitated quantitative work on Newton's laws, a study of momentum changes, of conservation laws, and of kinetic energy in Year IV. This required an empirical approach to force and motion in Year III, including some work on projectiles. The concept of force, however, is first introduced in Years I and II when various forces are encountered as pushes or pulls.

The empirical approach to forces, in which children encounter for themselves forces of various kinds to increase their experience, is typical of the work in the first year of the course. The year begins with a display of many different kinds of materials as part of the need to widen that experience. They start weighing and measuring for themselves. In the past the teacher sometimes began with a formal definition of density, followed by the measurement of its value for sand; at the end of this so many children could not see 'why' this should be done at all. In Year I they are led through the examination of blocks of material (all of a convenient size so that the work is not bogged down in tedious arithmetic) to feeling the need for density. They then weigh liquids and then air. At all stages simple single-pan lever balances are used to avoid the tedium of using chemical balances which, at this stage, merely impede the gaining of experience. Crystals are studied—

and grown by the pupils themselves. The first ideas are formed of crystals being made from 'piles of atoms'. There are various open experiments using magnifying glasses and microscopes. They learn to make careful measurements and to make rough guesses.



Microbalance used individually by pupils in Year I of the course and made from drinking straws and simple apparatus.

There is a beginning of statistics. The simple microbalance, made by the pupils themselves, is used for precise measurements—a hair is weighed with it—and at the same time begins to inculcate a respect and understanding for apparatus. Springs are investigated, but no longer are the pupils carefully restrained to the region where Hooke's law holds in order to avoid damaging the springs: these are sufficiently cheap and expendable so that they can make a real investigation. Of course it is really the regions where Hooke's law does not hold that are the interesting and significant ones! Pressure is studied, again empirically, and leads to the first ideas of a kinetic model. Brownian motion supports this and an oil film experiment enables the pupils to make their first atomic measurement. Finally in Year I there is a first introduction to the concept of energy and energy changes; in all, a year for gaining important experience which is useful later in the course.

Another end point in Year V is radioactivity: the random nature of the process emphasizes the uncertainties involved. The experimental work brings out the statistical nature of readings and helps to discourage expectation of a 'correct answer'. The work on radioactivity is used in the study of the atom, when atomic models are used to consider the place that models play in science. This work on radioactivity requires earlier a study of electron streams and the effect on them of electric and magnetic fields: the work on motion in a circle again finds a use in estimating e/m.

The work on fields necessitates earlier work on electromagnetism (in both Years IV and III), some electrostatics and some basic work on electric currents in Year II.

The study of the atom in Year V necessitates another important stream which runs right through the course: the approach to the atomic picture. Year I includes a study of crystals and the idea of piled atoms. The early work on pressure leads on to a molecular model of air, for which evidence comes from Brownian motion in air (an important observation which the project hopes every pupil will make for himself). Some surface tension experiments lead to the first atomic measurement when the pupils themselves make their own estimate of molecular size by spreading an oil drop on a water surface. A cloud chamber and a spark counter conclude Year I with a preliminary foretaste, or appetizer, of nuclear energy. The atomic picture is taken further in Year II with a preliminary look at molecular models of solid, liquid and gas; attempts are made to interpret the effects of heat. In Year III there is a more detailed look at the molecular model of a gas, Brownian motion is considered again and evidence comes from diffusion and also from Boyle's work on expansion. The work on mechanics enables quantitative work on the kinetic theory to be done in Year IV. There is a calculation of molecular speed and some work on bromine diffusion enables an estimate to be made of molecular diameter.

Wave motion is another important topic introduced experimentally in Year III where there is extensive work by the pupils using ripple tanks. This leads to waves, rays and some ray optics work, again experimentally developed and concentrating on image formation and culminating in optical instruments. The consideration of waves is returned to in Year V with a study of interference and some work on spectra.

The topic of energy pervades the whole course. It is met first in Year I, returned to year by year, each year being treated with a little more sophistication and becoming quantitative in Year IV. There is a concentration on energy transfers from one form to another.

It should already be apparent from this attempt to outline some of the content that a mere statement of syllabus can do little to give the flavour of the course, though it will doubtless be seen from the above how the topics chosen interlink and interweave between each other, how everything chosen is relevant to the whole.

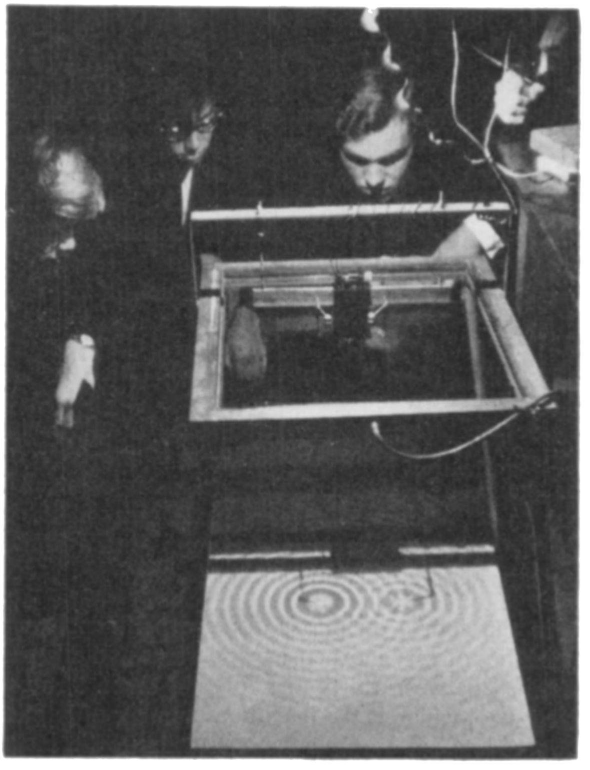
There are of course many topics omitted from the program which appear in most traditional courses. There is no Wheatstone bridge, there is far less calorimetry and no experiment finding the specific heat of brass in which the water carried across with the block just compensates for the heat lost on the way over, there is no statics and no direct reference to Archimedes, very little geometrical optics in the traditional sense, no coefficients-of-cubical-expansion-of-mercury-relative-to-glass. Doubtless some will deplore the loss and not wish to teach the Nuffield program. For others, they will find plenty of exciting new things, which trials have already shown capture the interest of the pupils, who gain from this work something of the fun of a scientific inquiry.

The range of materials

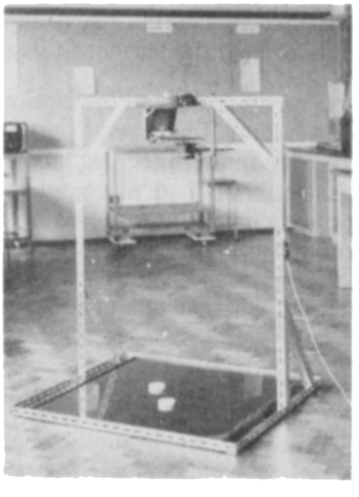
With the main emphasis on the method of teaching, the teachers' guides play a most important role in the program. These will appear in five volumes, one for each year of the course, together with an introductory volume on the course as a whole. There are separate experiment guides, again a volume for each year to assist in the class experiments to be done by the pupils and with the demonstrations by the teacher. There is a great wealth of new apparatus for this experimental work. There will be readers for the pupils to use themselves and volumes of problems for homework and class use. There will be visual aids of various kinds, including 8 mm casette film loops.

This material, developed by teachers for teachers, is now being tried out under classroom conditions. One cannot pay too high a tribute to the hundred teachers concerned who are involved in sending detailed weekly feedback. The program is being modified in the light of this practical experience so that on publication it will all have been tested.

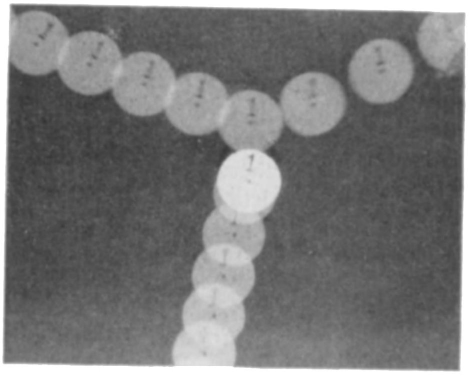
It is hoped that the final material will form a co-ordinated whole to be used by individual teachers as they think best. It should be emphasized that this is no attempt to impose a new orthodoxy. The Nuffield physics project has been doing a piece of research work: the extent to which the work is ultimately used will depend solely on its merits. Some will use the program as it stands, others may prefer to use parts of it. At least it will be a stimulus for further thought and development among the teaching profession.



Ripple tank for use by pupils, in groups of four, in Year III of the course.



(*a*)



(*b*)

Carbon dioxide magnetic pucks used for quantitative work on collision processes. (*a*) The pucks moving on a glass sheet with a Polaroid camera set up over them. (*b*) Strobed photograph of the pucks colliding.

Apparatus

The apparatus group in the Nuffield physics project has given consideration to the wide number of problems associated with school physics teaching. When the project began, there were over a hundred experienced teachers working in the various teams who fed in ideas and who made prototype apparatus. Some of these were very ingenious, but did not fit in with the general pattern which evolved. For this reason, they have not been incorporated, though many have been published separately, notably in *The School Science Review*, and will doubtless prove of great value to individual teachers. Those ideas, however, which fitted the general program had then to be developed so that they were commercially available, and this work has occupied much of the time of the apparatus group.

There will always be a place in English teaching for good teachers developing their own ideas and building their own apparatus. The last thing that the Nuffield project wishes to do is to discourage them, but the large majority of teachers do not have the necessary skill—or, above all, the necessary time—to make their own equipment and this is the reason for the insistence that the apparatus is commercially available. The project has obligations to *all* teachers, good and indifferent alike. Thanks to the very active co-operation that has gone on with manufacturers (and a limited number of firms in particular), the necessary apparatus is now available.

With the emphasis in the course on pupils doing experiments themselves, one of the needs was for large quantities of very inexpensive apparatus and this has led to the development of a number of 'kits', between thirty and forty of them. The magic number associated with these is thirty-two, which is the maximum number of pupils considered suitable for a Nuffield class. Some kits, for example the microbalance kit, include apparatus cheap enough for pupils to work individually. The electromagnetic kit contains the wherewithal to enable sixteen pairs of pupils to work with it. This kit contains all the necessary parts for over thirty different experiments and, for example, the d.c. motor which the pupils make and use themselves, is cheap enough for them to be able to take home and show their parents. Included with the kits are some general kits, one for each year of the course, which contain a large variety of miscellaneous items which it is necessary for the teacher to have in order to teach the course in the manner intended. Many of the items are things which can be obtained by other means, but one of the troubles of the past has been lack of time on the teacher's part and experiments have often gone by default. It is hoped that manufacturers will continue to supply these general kits to help the teacher in his task.

The project has also taken further the work initiated by the Modern Physics Committee of the A.S.E. in the design of certain basic equipment suitable for general purposes in a school laboratory: power supplies, amplifiers, scalers with timing facilities incorporated, oscilloscopes, meters and so on. So often in the past, schools had to accept industrial apparatus as being the only type available, but the oscilloscopes and scalers, for example, were not very suitable for schools and were often unnecessarily elaborate. Through collaboration with manufacturers, a great wealth of apparatus is now available. This will, of course, be of assistance to all teachers generally, whether or not they adopt the Nuffield program.

Attention has also been given to basic school apparatus, to the design of retort stands and clamps, to plugs and sockets, to spring balances and balances in general. Far too little attention has ever been given to the right tolerances in, for example, such things as weights and weight hangers. These have often been to a much closer tolerance than the rest of the apparatus justified; by getting the tolerances right schools can get substantially more for their money. Another good example of the work is rheostats. The catalogues of all the school apparatus manufacturers are full of an immense range of rheostats. For the average teacher it has usually been a matter of hit-or-miss and he has seldom known which to buy. The Nuffield project has standardized all its experiments on two rheostats (10–15 Ω at 5A and 330 Ω at 1·2A). Not only does this help the teacher, but it will also help the manufacturer who can concentrate on this limited range with the result that prices fall substantially because of the greater quantities involved.

In addition to giving detailed specifications on apparatus requirements, the project will ultimately issue a list of recommended apparatus for the assistance of teachers and authorities. This will involve work of assessment, which the project has undertaken to do.

Finally, the project will produce advice and detailed drawings of apparatus to enable enterprising teachers to manufacture their own apparatus in order to reduce costs.

Examinations

However much the teaching is directed away from facts and the reiteration of definitions, however much the concentration is on understanding and a critical approach to the subject, all this will come to nothing if customary examination papers are set with questions which begin, for example, by asking for a formal definition of specific heat, then a description of a standard method of measuring it for copper or brass or lead as the examiner decides (despite the fact that no practising physicist would ever dream of using such a method), followed by a numerical example solved by substitution in a formula learnt by heart. It was essential that there be a public examination in tune with the whole approach.

The project has been fortunate in having a very active examinations group under Dr. H. F. Boulind which has been devising new questions and specimen papers suitable for each age of pupil. Perhaps the most encouraging aspect has been the close co-operation with the Department of Education and Science and the G.C.E. Examining Boards, who are making arrangements for special Nuffield examinations at O-level.

The Nuffield physics project and the engineer

Much has been written in recent years about the national need for more engineers, and the Nuffield project has certainly not forgotten its obligations in this direction. The tendency at the present time is away from early specialization and it is hoped that all children in secondary schools will do a physics course: the Nuffield program is intended as part of 'science for all'. It is unlikely that there will ever be any wide adoption of applied science or engineering as an additional subject at O-level. The physics program must therefore incorporate respect for engineering, for some of its problems and for its achievements.

As was discussed recently in the editorial of *Engineering*,[15] it is the 'how' (the experimental method) rather than the 'what' (the prescribed ground to be covered) of Nuffield syllabuses that will influence schoolboy attitudes to technology. 'From the outset the schoolboy is encouraged to get to know the feel of the basic materials and to see that getting his hands dirty in the process in no way limits intellectual stimulation.'[15]

There are many places where respect for engineering is inculcated in the course. Even in Year I, the simple microbalance does much to stimulate interest in design. The electromagnetic kit, for example, with its emphasis on pupil participation, gets the children doing important work with their hands. The energy conversions kit has the pupils handling dynamos, motor, steam engines and turbines, and the topic of energy which pervades the whole course could be no more fundamental for the future engineer. It is of course important that the simple models used in the classroom should be related to the outside world and discussions are now being held with industry on the production of 8 mm film loop casettes relating, for example, the turbines and motors used in the course with the large commercial versions used in engineering.

The reaction of those engineers who have now seen the Nuffield material encourages us in the belief that the work being done in the project will in fact do much to encourage the awareness and the respect for engineering that everyone would like to see.

Questions

There are certain questions that any account of the Nuffield physics project immediately brings to mind, and it seems wise to anticipate some of these.

(i) *Is the Nuffield project designed primarily for independent schools?*

In fact the reverse is the case. The course is a five-year one intended for grammar school children aged 11 to 16. The Nuffield program can be used in independent schools, but they will have peculiar problems to solve for themselves with their intake at 13. It suits grammar schools ideally at the moment, it will suit independent schools as soon as preparatory schools all start teaching Nuffield Years I and II.

(ii) *It sounds a very rigid program. Do I have to teach it in the manner suggested?*

Of course not. The project has merely been a major research program, produced by teachers for teachers to use as they wish. Some will adopt it, some will use parts of it, some will prefer to continue with traditional methods. It is offered as a contribution to the many problems that beset science teaching today.

(iii) *What about a class textbook, is there not going to be one?*

No. In fact a textbook in the conventional sense is not really compatible with the suggested methods, which encourage the pupils to find out for themselves. A conventional textbook gives away all the answers beforehand.

(iv) *Is it true that the experiments are no longer accurate?*

It is true that in the initial stages there is a great deal of experimental work aiming at giving a growing acquaintance, but there is plenty of quantitative work in later years. If by 'accuracy' you mean are the children going to measure the specific heat of brass to several places of decimals, the answer is certainly no. There is more attention given to orders of magnitude and also more attention to the nature of measurement and an assessment of what the real accuracy of a given experiment is. How often in the past children have given the specific heat of copper as 0·09341 merely because their logarithm tables gave it to four decimal places!

(v) *Is the program better suited to boys than girls?*

There are doubtless parts which have greater appeal to boys, the electromagnetic kit for example, but the needs of girls have been kept in mind and some parts, the ripple tank work for example, has been especially successful with them.

(vi) *Do I have to be a teacher of experience before starting such a program?*

Most certainly not. Experienced teachers will be familiar with many things in the guides because these were written deliberately with the inexperienced teacher in mind. In fact some of our best trials have been done by people fresh to teaching without any preconceived ideas.

(vii) *Is it easy to teach?*

It is certainly fun for the pupils. It is hard work for the teacher though the trials tell us that it is very much easier the second time round!

(viii) *Are m.k.s. units used?*

I might have guessed that question would come up! Practical units are used throughout the course—the ampère, the volt and so on. In the first year use is made of British units, but there is a gradual introduction and weaning to the metric system. The dyne is not used, but the newton is met early on and has certainly presented no trouble in the trials.

(ix) *Can one start teaching the course at any stage of it?*

It is a five year course so the right place to start is Year I. It is certainly possible to start at Year III, it would be most unwise to start at Year IV and quite impossible at Year V without having done the previous years.

(x) *I teach bright pupils. Could they get through the course in two years?*

It might be possible for bright children to complete the course in four years instead of five, and doubtless there will be many experiments on these lines. But to condense it to two years would be quite impossible if it were to be taught in the manner intended. There is much emphasis on pupils making their own investigations and this does require time. There have been pupils getting through conventional O-level courses in one year in the past by cramming factual knowledge; this would be quite impossible with the Nuffield program with its emphasis on understanding, away from rote memory.

(xi) *How much would the apparatus cost?*

This is not an easy question to answer at this stage. First, there has been little or no competition between manufacturers so far. Second, the apparatus has been required in relatively small quantities and large scale production will reduce costs. At the moment the cost is about £750 per school per year of the course or, say, £3000 for the whole course. This does not make allowance for what the school may already possess or the teacher may be able to make himself. It is of course only a small sum compared with the total bill for education and an encouraging aspect has been the willingness of Local Education Authorities to pay for the necessary apparatus needed for the present trials.

The cost of the apparatus has been kept low and, in many instances, reduced on conventional costs, but it is the need to provide apparatus for pupils to use themselves that inevitably produces the above figure. It should be remembered that a high proportion of the cost is a once-for-all payment.

(xii) *Are laboratories necessary for teaching Nuffield physics?*

The Nuffield course does require the use of a laboratory; a lecture room is not suitable. The only other requirement is plenty of space for storage.

(xiii) *What about A-level?*

The Nuffield Foundation has already begun to give consideration to the problem of A-level. However, the Nuffield O-level course as it stands would be a perfectly satisfactory basis for either a new Nuffield A-level course when it is produced or for a conventional physics course. In the latter case, there would be certain omissions which would have been covered in the old O-level, but this would be offset by a deeper understanding of certain topics and a knowledge of others which have in the past been confined to A-level.

(xiv) *How soon can we start using the course?*

All the material will be published in April 1966 and freely available for use in schools from September 1966 onwards, and special alternative Nuffield O-level examinations will be available for those schools.

Conclusion

This article has attempted to explain the reasons for the Nuffield physics project and to give some details of it. The articles in the *Bulletin*, quoted at the beginning, suggested the need for change and this research work is an attempt to help the necessary reform. How widely it comes to be used will depend on its merits.

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