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The Nuffield Science Teaching Project, which began at the end of 1961, is about to publish O-level courses in physics, chemistry and biology. This article describes the construction of the physics course and the way in which the various concepts of physics have been linked together in it. It also indicates some of the steps which have been taken to develop ancillary materials and some of the problems that will have to be solved before the course can be widely accepted in the schools.

Figure 1 In simple experiments on radiation the back of the pupil's hand is used as a detector. (From the Esso film *Elementary Experiments in Heat Radiation.*)

FOR more than four years a small band of men, with the assistance of a large number of schools, has been engaged on an experiment in education which has no recent precedent but which is certain to have a profound effect on the teaching of physics and, for that matter, on the teaching of science as a whole in British schools. This is because the forthcoming output of the O-level physics team (which is embodied in the collection of books to be published in the course of this summer and in collections of apparatus being made available by suppliers of scientific equipment) is more than just a course which can be followed by teachers wishing to give O-level pupils a feeling for what physics really is. It is also a model of how a self-conscious and deliberate innovation can be carried out within the curriculum; of how apparently outrageous and daring ideas can be made into a workable programme of teaching in the ordinary classroom; of how examinations at O level can be matched accurately to a new teaching programme; and of how the process of change can be made so intimately to involve working teachers that in some real sense the curriculum becomes the possession of the schools and not some treadmill upon which they must struggle for survival.

The physics programme has its roots in the work done by the various voluntary bodies in England in the late fifties and in particular by various committees of the Association for Science Education and of The Institute of Physics and The Physical Society. At that time a great many practising teachers and a great many of those in universities and industry who were concerned with the quality of education had become dismayed by the static character of the then curriculum. For these were still the days of Nicholson's hydrometer, the density bottle and Helmholtz's galvanometer. Briefly, it seemed that too little was being taught about the new and more exciting developments in physics, that too much had needlessly survived from an earlier age and, above all, that too much attention was being paid to what are sometimes called 'facts' and too little to the understanding of what physics is all about. A diagnosis was quickly followed up by an attempt at cure, and indeed the Association for Science Education committees produced a number of documents intended to bring to the attention of working teachers the need for some renewal of their curriculum and for some change in the attitude of many teachers towards the teaching of the subject.

But there is a limit to what can be done by voluntary committees meeting at week-ends and whose individuals work late into the night after the marking for the following day has been finished. By September 1961 it was becoming plain that the progress which people were looking for could only really be achieved if the teachers concerned with these new developments were able to spend all their time working hard in preparing new materials, trying them out to make sure that they worked and then writing them out in a form that could be of day-to-day service to teachers in all kinds of schools. The trustees of the Nuffield Foundation were quick to recognize that this was a field in which money could be spent with great advantage. A large sum was set aside to recruit teachers to a team being formed under Mr D. McGill (seconded from the Scottish Education Department). With the advice of a distinguished committee under the chairmanship of Sir Nevill Mott, a start was made on hammering out a programme that would lead to a fully integrated O-level course in physics suitable for pupils in grammar schools.

What happened in Britain is representative of what happened somewhat earlier in the United States. In the late fifties a number of curriculum development projects were begun in North America, the first and best known of which is the Physical Sciences Study Committee. There is no question that the interest in curriculum reform now apparent in Britain has been strengthened enormously by the American demonstration of what was feasible.

Historically it is important that the role of the Nuffield Science Teaching Project has been to accelerate a movement that was already under way in 1961 and which would, in due course, have led to a great many of the innovations now being introduced. It is also, however, important that the acceleration of this change which the Science Teaching Project has brought about is so great that it is hard to see how the course now being published could otherwise have been developed in less than several decades.

The object of the development, which goes to the nature of the subject, probably more clearly expressed in physics than in chemistry and biology, is somehow to bring science to life for pupils between 11 and 16. The organizers—first Mr D. McGill and then, after his death in March 1963, Professor E. M. Rogers—have been rigorously concerned to include material that helps in the understanding of physics and to exclude material which may be a part of physics but which is not directly helpful in the process of deepening understanding at this tender age. Then, to

Figure 2 The Westminster electromagnetic kit enables pupils (13–15) to demonstrate all the important phenomena themselves. The electric motor and ammeter seen here were built by the pupil; this increases his self-confidence and understanding. (From the Esso film *The Electromagnetic Kit*.)

ensure that pupils understand what they are expected to learn, experiment is made dominant; and pupils do for themselves experiments which have often previously been regarded as demonstrations for the teachers—or even sometimes, things to be looked up in books. Finally, because it is unwarrantable to assume that pupils of this age are already seriously addicted to physics as a life-long discipline, every effort has been made to see that the course is fun—something to enjoy. This guiding principle is splendidly epitomized in what Donald McGill wrote at the top of the first sheet of paper to be circulated within the physics team:

"*Concerning the nature of things.* The richness and diversity of our world: solid, liquid and gas; crystal and powder; metal and non-metal; with physical distinctions made by volume and density; compression and stretching (elasticity and flow); temperature and the effect of heating, including expansion and change of state. The light which studying these physical changes throws upon the underlying atomic and molecular structure and mechanisms."

Plainly this noble set of principles is demanding on everybody concerned—on those who develop the course, on the teachers who try it out and on the pupils who become involved. This is why perhaps the most remarkable feature of the programme now reaching its fruition is that all those who have been concerned with the trials in the schools speak with pleasure of their experience. It has been an exciting enterprise. How do these principles reflect themselves in the structure of the course which has been worked out? Working teachers will not be satisfied with a quick answer but will (and should) want to read the five volumes of the teachers' guide in detail before deciding how pertinent the work will be to their own practice in the classroom and before deciding how to make use of it. But a number of features of the course are of more general interest to teachers, to those concerned with the products of the schools and to those concerned with the process of curriculum development as such. This then is an outsider's account of what Nuffield physics is like.

Pupils begin by handling materials—and in the process gain something like an instinctive feeling for the meaning of density. They look at crystals being cleaved. They grow crystals. They drop drops of oil on water and see the thin film of molecules spread out to cover a gigantic area. They make atomic models out of polystyrene spheres. They see the tracks left in a small cloud chamber by atomic particles. They are left with a conviction that matter is not as simple as it would seem to be at first sight and with a receptiveness for the sequels to this story that come at the end of the course—electrons, atomic particles and the like.

This looks like the deep end of the swimming pool, but experience in the schools has shown that it is by no means a formidable beginning to a physics course for there seems to be much in favour of the boy or girl sensing something of the excitements to come—to exploit his willingness to think of himself as a grown-up scientist.

Another feature of this starting point, which will seem to the outsider to be a daring innovation, is that pupils are encouraged to think of physical quantities in terms of the orders of magnitude which a professional habitually uses. For example, in working out the area occupied by a single molecule of oil in the oil-drop experiment, the pupils approximate a circle by a square, and a sphere by a cube. This saves trouble when they are unhandy with the arithmetic of π but is also a comforting assurance that there is no need to bother about the decimal places in a calculation whose real interest is the number of noughts that follow after the decimal point. Professor Rogers has introduced us to American 'Fermi questions' to indicate the sort of rough approximation that a person must use in answering the question "What is the power output of a French horn?" or "How much does the Mediterranean weigh?" To be sure, eleven-year-olds do not tackle questions like that, but it is intended that they should be confident in the value of methods of calculation which give them answers to the nearest power of ten, in calculations of lengths, masses, times and so on.

This first year also includes an attempt to make the concept of pressure vivid, with U-tubes which measure gas pressure, attempts to guess at the height of the earth's atmosphere and a quantitative theory of how all this could somehow be explained by the movement of atoms—a theory which is backed up by experiments on diffusion and with atomic models; and finally this first breath-taking year concludes with a discussion of energy—the idea of work and some idea of how bewildering are the different ways in which one form of energy can be converted to another.

Energy is the theme running through the whole of the five-year course, which is only right and proper. The Nuffield course does, however, differ from what might be expected by not taking the Principle of Conservation of Energy for granted. Indeed, only in the fourth year of the course is the assertion made as if it were a law of nature. Until then pupils are encouraged to feel that the inter-conversion of different forms of energy is one of the constant preoccupations of physics but they are discouraged from believing that the interconversion is always numerically exact until they have themselves carried out the experiments on which such an assertion must be based. Such, the argument is, is the respect due to a powerful theory.

Electricity makes its appearance in the second year of the course and pupils see the tracks of a stream of electrons in a vacuum for the first time in this early stage. But there is still something to challenge the imagination, not something to be 'learned'.

The third year is perhaps the most demanding of all. This is where pupils begin to practise physics with some of the logical exactitude of the professional. It is worth remarking that this transition accords well with theories of learning. This, the argument goes, is the age at which more or less unstructured curiosity is spontaneously replaced by a wish to construct theories around abstract concepts.

In Nuffield physics, year III means waves, optics and a first taste of motion, Newton's first law and some vivid hints that the second law is lurking behind it all, ready to explain why heavy things accelerate less quickly than lighter things under the action of the same force. The waves are made by pupils in ripple-tanks for experimental use and hand stroboscopes make interference patterns stand still. Optics is neatly done with lenses of a particularly convenient design. Pupils make their own telescopes and microscopes by moving the necessary lenses in and out along a portable lens holder (hardly an optical bench) so as to acquire an informal feeling of how lenses work. And they also learn by practice how to time the movements of trolleys; they have a length of paper tape running through an electrically driven vibrator which marks the tape fifty times a second.

The fourth year of the course is where classical mechanics comes into its own and where the whole apparatus of Newton's laws is sustained in the classroom by patient experiment with moving trolleys. This, if teachers are brave enough, is where pupils will measure the speed of an air-gun pellet by timing its flight and where they will use cameras and flashing lights to record the movement of objects such as steel cups which are supported on glass plates by a cushion of carbon dioxide and are thus able to slide more or less without friction. This preoccupation with Newton's laws is characteristic of the physics course and gives it its stamp. The hint at atomic theory in the first year and the concern for the reality of electrons in the last year of the course are consequences of the view that it is unwise to let pupils reach O level without knowing something of the modernity of physics; but the insistence on the importance of the classical laws of mechanics, not merely with explanations of mechanics, as examples of how laws come to be constructed is a consequence of the view that physics is worth while only if it is properly understood.

Mechanics is also conspicuous in the fifth and last year of the course, when Newton's laws are used to throw light on the whole processes of the movement of the planets around the Sun and of the movement of the Moon around the Earth. (This, too, is where Nuffield O-level students derive v^2/r for the force involved in circular motion—a feat hitherto reserved for sixth-formers.)

The fourth year of the course is also the one in which the cap-stone is put on the discussion of inter-conversion of energy by means of the relation between potential difference (in volts) and energy transfer per unit of charge (in joules per coulomb).

Dealt with superficially, such a programme could be valueless as physics. The guarantee of its merit is in the way in which each subject must be carried out experimentally before the pupil's eyes, usually with his own hands. Indeed in the event the course is a demanding one. At the beginning at least, teachers are urged not to shorten the five-year course into four, though they are also urged

Brain teaser

A long light cord passes over a light frictionless pulley. A bunch of bananas is tied to one end of the cord; at the other there is a monkey whose mass is equal to that of the bananas.

If the system starts at rest, with the bananas higher than the monkey, can the monkey reach the bananas? *Answer on p.* 18

not to start teaching it anywhere but at the first or third years, and they are urged to give themselves plenty of time to prepare the experiments.

The evolution of this course would not have been possible without the trials which have been carried out in sixty schools and without the co-operation of the local authorities which provided the necessary equipment. At the same time, the collaboration of the apparatus manufacturers has been necessary and invaluable. From the beginning of the O-level physics programme Mr John Lewis of Malvern College has kept continuing liaison with the manufacturers and has been personally responsible for the simplification of a great many designs and for the cheapening of the cost of a large number of the items of equipment. Even so, there is no shying away from the fact that Nuffield physics is comparatively expensive. So would be any programme of physics which relied as much as this does on experiments carried out by pupils for themselves.

This feature of the course is likely, in the long run, to be one of its most lasting merits. The details of what items are included and in what order may, in due course, change. But the way in which pupils are made to rely on experiment will create a pattern of laboratory work of great interest and will—with luck—tempt a great many of those who have previously been inclined to think that science is to be found in books to reliance on the skill of work done with hands in laboratories. This, in the long run, may be part of an answer to the shortage of engineers.

The evolution of this programme would not have been possible without the collaboration of the examinations boards as well. Before trials began in the schools the General Certificate of Education examination boards agreed to provide a special Nuffield paper for pupils from the trial schools. This made it possible to evolve new styles of examining. The first O-level paper was set in 1965 and has done much to justify the belief that this kind of physics does deepen understanding. Happily, the examination boards have now agreed to continue providing a Nuffield paper in the years up to 1971, which implies that schools embarking on the Nuffield course in September 1966 will be able to enter their pupils for a properly matched examination. In the long run, of course, the ideal is that the examination boards should incorporate what they consider appropriate of the Nuffield courses into their own syllabuses.

Figure 3 The Worcester circuit board is used by 12-year-old pupils to learn about elementary electrical circuits from first-hand experience. Here they are shown how they could 'blow' their fuse of wire wool. (From the Esso film *The Worcester Circuit Board.*)

This, indeed, is how it is hoped other interests will deal with the materials. Teachers themselves will wish to make changes. Sooner or later there will have to be another programme to produce another O-level physics course, for the curriculum must be dynamic if it is to stay alive. (The Nuffield courses themselves will be revised by the team of men who produced them.) It is also essential that there should be opportunities for teachers to study the new materials and to comment on them in an informed fashion, which implies an immense need of what is commonly known as in-service training. Fortunately one of the results so far of the Nuffield initiative has been the way in which local authorities have agreed to provide conferences and courses for their teachers. It is hoped that this pattern will grow and become permanent for that is the best assurance that the community of physics teachers in the schools can become what it should be—an arbiter of what is taught and how.