Resource Paper 26
1 August 1969

ORIGINAL: ENGLISH

UNITED NATIONS/UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

WORKING PARTY ON THE IMPROVEMENT OF SCIENCE EDUCATION WITH SPECIAL REFERENCE TO DEVELOPING COUNTRIES*

(UNESCO Headquarters, Paris, 15-19 September 1969)

APPARATUS AND OTHER AIDS IN PHYSICS TEACHING

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* Organized jointly by the United Nations Advisory Committee on the Application of Science and Technology to Development and the Division of Science Teaching, UNESCO.

Introduction

Such is the nature of physics that a course devoid of experiments, and devoid of apparatus for those experiments, cannot be called an educational course in physics. On the other hand good experiments and ingenious apparatus must always be subservient to the course: the tail should not wag the dog.

Twenty years ago, a syllabus was considered the basis for a science course in schools. This consisted of a list of topics to be studied, chosen to provide some basic facts about the subject, often as a basis for further education, irrespective of whether or not the child would be studying the subject again. This encouraged the belief that science education amounted to the acquisition of factual knowledge.

In recent years greater attention has been given to our aims in teaching science: why science is taught. The reasons are two fold: first, to show pupils what science is about and how a scientist thinks, stressing the limitations as well as the scope of science; secondly for the sake of the technological advances, which are possible in a scientifically educated country and which lead to increasing well-being in that country.

If a course aims to show how a scientist thinks and something of the nature of science, this inevitably affects both what is taught and how it is taught. For this reason there has been a movement away from the syllabus and an increasing realisation that a complete programme is necessary. A syllabus was often a list of topics which might be examined at the end of a course; a programme suggests how the course should be developed at each stage, the depth to which it should be taken and how the subject may be presented. Importance must obviously be attached to the subject matter and the way it develops as a logical whole, but even more important is the way in which the teacher handles the subject matter.

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The Physical Science Stud Committee in the United States was the first to stress the importance of a programme rather than a syllabus, though the USSR had seen the need to give guidance to teachers in much greater detail than was contained in a mere syllabus. A further stage in the evolutionary progress has been realised by the Nuffield Foundation's Science Teaching Projects in the United Kingdom, where most of the work is directed at the teacher to help him to achieve a standard.

Whenever a country decides to change its science teaching, it must decide first why it is teaching science at all. The aims of science teaching have already been discussed in another paper and will not therefore be mentioned further here. Once those aims have been established a country develops a programme to achieve those aims. Inevitably it considers what aids it will need - and what aids it can afford - to achieve the objects of their programme.

Talk-and-chalk or experimental science?

Traditional courses in science used to rely on the mere acquisition of factual knowledge - definitions to be learnt by heart, formulae to be memorised and a series of mechanical rules to be remembered in order to answer problems. Too often chemistry amounted to learning the properties of gases; too often biology consisted of drawing labelled diagrams and learning names for different parts. A typical question in a physics examination might be:

> "Define coefficient of linear expansion.
> How would you measure it for a metal rod?
> A steel tyre has a diameter of 99.7 cm at 15°C. To what temperature must it be raised to enable it to be put on a wheel 100 cm in diameter? (Coeff. of linear expansion of steel = 0.000012 per °C)."

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The definition is learnt mechanically. The description of the experiment can be memorised irrespective of whether the pupil has ever seen the apparatus. The numerical question merely requires substitution in a formula. The kind of school work done in preparation for such questions is not likely to do much to encourage more pupils to become scientists, nor does it give any understanding of the nature of science.

Science is based on experiment and, if pupils are to get the feel of science, some experimental work must be done. Factual knowledge can be given with the use of talk-and-chalk alone, but real understanding cannot be based on dogmatic assertion by the teacher : the evidence must come from experience. A good science programme will encourage pupils to think for themselves, to look for evidence and to use their judgment; and only if the evidence is produced through experimental work can the judgments be formed.

Accepting that experiments should be part of the course, we must decide what kind of experimental work should be done. Routine measurements or "verification" of a law are of limited use : the number of different ways that were devised for finding the focal length of a lens may be a tribute to the ingenuity of examiners but they do not teach much about the nature of science. Equally "verification of Boyle's Law" teaches little about scientific investigation: the pupil knows that the teacher wants a straight line and he will do his best to give him one whatever his readings!

There can be a place in a course for a precise measurement of some constant, teaching thereby something of the discipline of a scientific investigation, the need for precision and the elimination of errors, but not all the work should be of this kind. Whenever a child can carry out an investigation and can draw his own conslusions, he will have a far greater understanding and the knowledge he has acquired will be his own and not second hand.

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For this reason, whenever time allows, experiments should be done by the pupils themselves rather than as demonstrations by the teacher. There will be occasions when the cost of the apparatus requires that the experiment be a demonstration. A course based on a series of such demonstrations may testify to the skill of the manufacturer in making good equipment and may do much to impress both the teacher himself and his pupils with his skill in carrying out a demonstration, but he will do little for the good name of science and may not encourage pupils to study science themselves. It is personal involvement that is more important than efficiency or precision. These principles inevitably affect the laboratories and the apparatus for use in them.

Laboratories

Even in the more sophisticated countries there has been a tendency in recent years to provide more simple laboratories than was customary ten, twenty, or thirty years ago. The important thing is space. Two major requirements are (1) flexibility in furnishing and layout, (2) ample accessible storage facilities.
Water supplies, sinks and gas are necessary, especially for chemistry and biology. These services are most economically provided around the walls of the laboratory. Most modern physics courses will require an electrical supply: it is more economic to procide plenty of mains sockets around the walls and to use portable transformers to provide low voltages than to go to the heavy and unnecessary expense of piping low voltage supplies around the laboratory.

The furnishings should provide a flexible layout: it is far better and cheaper to have robust movable tables than fixed ones with complex supplies. Such tables should not have drawers or cupboards, they should be light enough for two children to carry them, they should be the same height as any fixed benches around the wall. Blackout is invaluable and half blackout probably essential, particularly in laboratories used for physics.

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With the modern tendency to provide large quantities of simple apparatus to enable pupils to do experiments themselves, plenty of storage space is essential. A store room must be adjacent to the laboratory so that the apparatus is easily accessible. Expensive, glass-fronted, fixed wooden cupboards are an anachronism. Simple, carefully designed storage units are important and more attention might be given to this than has been customary in many countries in recent years. (Some examples of modern storage units will be on show during the conference).

Apparatus

"Hear and forget, see and remember, do and understand". If it is accepted that understanding comes through personal involvement, apparatus for pupil experiments must be available in large quantity.

Fortunately in Chemistry the same basic apparatus, the same glassware, can be used throughout much of the course. In any programme use should be made of local material: it would be absurd in Zambia to import a special chemical from London when a suitable alternative is available locally. Likewise a wise Biology course will make the maximum use of local material. Unfortunately such is the nature of Physics that apparatus in some quantity is necessary for its proper teaching, but much of the apparatus can be very simple in design.

The Physical Science Study Committee in the United States started the trend towards low cost apparatus. The Nuffield Physics Project in the U.K. has developed a large number of kits of apparatus for use in their programmes. The electromagnetic kit, for example, consists of a large number of small inexpensive items in sufficient quantity to enable a class of 32 pupils to do the experiments working in pairs. The kit is carefully designed to do between 40 and 50 different experiments - and it can therefore be used for many weeks of a school course. Its versatility,

and the fact that it can be used over a long period, makes it a good economic proposition. Some of these Nuffield kits will be on display during the conference.

It will be noted that much of the English apparatus is more robust than the P.S.S.C. equivalent apparatus. This is due to the different organisation of educational funds in England and the U.S.A. Much P.S.S.C. apparatus is deliberately inexpensive and expendable as American schools tend to have a high annual budget for equipment, whereas in England the tradition is to spend less annually but to prefer a larger initial outlay. For this reason, much Nuffield apparatus has been designed to last for 5 - 10 years, but costs more initially. Every country developing its own programme has to decide for itself whether to have higher initial costs and lower running expenses or the other way round.

For demonstration apparatus, the important factor is versatility. Few countries will be able to afford an expensive item of demonstration apparatus which is only used for one experiment. On the other hand, a scaler which can be used for a large variety of radioactive experiments and which can also be used extensively as a millisecond clock by incorporating a thousand cycle oscillator is an attractive proposition.

There was a tendency at one time for manufacturers to make an item complete in itself. This is not the most economic way of providing the teacher with the equipment he needs. For example, a general purpose power supply and a general purpose aplifier, both of which can be used in a large variety of different experiments, is better economy than building a power supply and an amplifier into every piece of apparatus requiring such units.

Simplicity is another important factor in teaching apparatus. Equipment designed for industrial use is not always suitable for schools. Simplified versions of industrial apparatus, for example oscilloscopes, may lead to better teaching and be a considerable economy.

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In England, the contribution in the last ten years which has probably lead to the greatest advance in physics teaching is the acceptance of voltage supplies other than a dry cell or an accumulator. The willingness to use mains operated power supplies - transformers and d.c. power supplies up to 5000 volts - has transformed secondary science teaching. Safety devices of various kinds make these suitable for school use and they extend greatly the extent of experimental physics that is possible.

Any country developing a new science teaching programme must necessarily decide for itself a definite economic policy over apparatus.

Textbooks?

Teachers following traditional courses almost invariably required a textbook for pupil use. The new American programmes continued to rely on a textbook. The Nuffield Biology course also relies on textbooks, but the Nuffield Physics and Chemistry courses do not. Much thought has been given to the place of a textbook in a science course, and there is probably a trend away from textbooks in the traditional sense.

No one would question the place that the textbook has for the university student. What is questionable is how necessary a textbook is at the early stages of a secondary school course.

If the tendency in science teaching is to encourage critical thought and to discourage an authoritarian approach to science, how can we expect a boy or girl to find out something about electric currents in order to make the knowledge his own if the answer is clearly states three pages further on in his textbook? The role of the textbook is changing. It is becoming much more a background book, pleasantly illustrated and easily readable, relating the experience of the classroom to the outside world.

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Another role of a textbook was, in the traditional courses, to provide a collection of questions for the pupils, often for use as homework. There continues to be a need for such questions. Questions were incorporated in the P.S.S.C. textbook. In the Nuffield Physics Project, separate questions books were written for each year of the course. Thus the material for the pupil consists partly of Question Books and partly of background books.

Teachers' Guides

Now that new programmes lay much emphasis on the method of teaching, a Teachers' Guide must play a most important role. A syllabus alone gives no indication of how deeply a topic should be expored; phrases like 'elements and compounds', 'radioactive disintegration', 'interference effects', all of which have appeared in some syllabuses, could be very differently interpreted by different teachers. They need guidance.

Teachers also need to know why certain things have been included in any well planned programme where something studied in one place is an essential basis for something coming later. Such a guide can include experimental details which will enable the teacher to get the most effective use out of the apparatus. He can be advised on the best way to set up an experiment and be given hints and instructions, where it may not be at all advisable to give so much detail to pupils. If laboratory work is to be a true investigation in which the pupils feel the information acquired is their own, precise instructions similar to those in a 'cookery book' can do harm, even though at one time it was customary to give them to pupils. The instructions, however, need to be somewhere - and the right place is the Teachers' Guide.

Such guidance does enable an indifferent teacher to achieve a standard. It need not be a restraint on the good teacher who will always want to develop new methods of his own, and should be encouraged to do so, but a guide can make all the difference to a young or inexperienced teacher.

The P.S.S.C. scheme was the first to write a detailed guide, but it tended to be mainly subsidiary to the pupils' textbook and outlined solutions to questions. The Nuffield Projects have taken the process much further and their main books are in fact the guides written for teachers. The Nuffield Science Teaching Project believed it could exert its greatest influence through the teacher rather than directly to the pupil. It is likely that programmes in other countries will all produce detailed guides for teachers.

Films

The powerful contribution that films can make to education is well known, and it is likely that use will be made of them in any new science teaching programme.

Elaborate experiments that could never be shown in a classroom can be put on film for pupils to see. Films relating the classroom work to industrial applications are always an asset. Films using special techniques have exciting possibilities: one of the most remarkable teaching films ever made is "Frog Development - Fertilization to Hatching", made by the Educational Services Incorporated in the United States. By time-lapse photography, one watches cell division through a microscope: the creation of life for the child to see.

The 8 mm casette film has already proved itself a powerful aid in science teaching - and there will be much development of this medium in the next ten years.

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There are dangers in relying on films too much. Perhaps the worst 8 mm casette film is one showing an animated drawing of a rope being oscillated to show wave motion. Care must always be taken over animation as it is too easy to build incorrect details into it, but, above all, it is absurd to put on film what is more cheaply shown by having a real rope in the classroom.

There is a tendency for every new science teaching project to want to set up a film studio and start making films straight away. Film making is very expensive. There is a danger of over-proliferation: there are already too many bad films available and a sub-standard surfeit may not be an educational advantage. A country starting a new science teaching project would be wise to examine the films and film-loops of other projects before embarking too quickly on its own expensive film making process.

A selection of film-loops will be available for viewing during the conference.

Films for teachers

An interesting development in educational films in recent years has been the series of films made in the United Kingdom by Esso Petroleum in association with the Nuffield project. These films are intended for teachers and are quite unsuitable for showing to pupils.

The problem of teacher training, or teacher re-training, is always important, and it becomes an essential part of any new science teaching programme. Films showing new techniques, explaining some of the philosophy of the course, can make a major contribution to this. An example of one of these films will be shown to the conference.

Such films, however, can cover in fifteen minutes work which might take the pupils half a term. It would ruin the teaching if the films were seen by such pupils and much stress is laid on their being suitable only for teachers. They have been extensively used on courses in the United Kingdom and throughout the world. They have been deliberately kept simple in order to keep costs down. They are made by practising teachers, rather than by Nobel prizewinners, in order to give other teachers confidence: "If Bill or Jack can do it, so can I". These films have proved powerful aids and their influence extends far beyond the limited audience that sees them: they can affect many generations of children.

Conclusion

This is an exciting time to be a teacher of science with many developments taking place. Fortunately each successive project in each new country becomes cheaper than those that have gone before as they can build on the experience of others as they produce programmes for their particular need. Let us hope that this world-wide activity will produce future generations of young people with a greater understanding of what science is about, as well as encouraging more and more to become scientists and engineers, on whom the future prosperity of mankind will inevitably depend.
