A Review of Some Overseas Science Teaching Projects and the Implications for South African Science Teaching Methods

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THE LAUNCHING of Sputnik I by the Russians also launched the Western World on a critical appraisal of existing science teaching methods and the content of syllabuses. From this research it became clear that money would be needed to finance experimental projects. First in the field of research was the United States with the P.S.S.C. research into physics and the rival philosophies of the Chem Studies and Chemical Bond Approach.

In American High Schools the sciences are normally taken towards the end of the high school period and for a single year. The approach is then aimed at a student already rather sophisticated and who will spend only one year in a particular discipline before going on to university. This is a pattern unfamiliar to South African High Schools and also to schools in Britain. It is, therefore, to Britain we should turn to see what is being done in a school system more nearly approaching our own.

Before looking to the science projects of Britain for inspiration for our own teaching, we should consider in some detail the school systems in which these projects have been developed. We may then see more clearly to what extent it is possible to apply these methods in South Africa and to what extent the subject matter can be covered in our schools.

In England pupils enter school in the year in which they turn five, spend three years in the Infant Schools followed by three years in the Primary Schools before moving on to the High Schools at 11+. Of those passing into the High Schools, whether they be Comprehensive Schools housing a normal cross-section of the academic abilities, or the Grammar type school catering only for the more academic type of pupil, only about 25% will eventually write the G.C.E. O-level examination which is normal school leaving examination at the end of the compulsory school period for those of some academic ability. The remaining 75% may leave school at the age of 16 with perhaps no certificate at all or one of the less rigorous syllabuses will have been followed to obtain a Certificate of Secondary Education. In the sciences these latter certificate examinations are of a level comparable to our Standard 7.

Of the 25% of students of higher academic abilities not all will necessarily take science courses. Of those that do take a science course physics has the greater following, with chemistry and biology being taken by approximately equal numbers. Those staying on after the compulsory period of attendance specialize in two or three subjects for a minimum period of two years after which they write the A-level examinations which are a prerequisite for entrance into a University, though the passing is no guarantee that admission to a University will be granted.

In Scotland children enter school in the year they turn six. After seven years in the infant and primary schools they enter the high schools. As in Britain approximately 25% of those entering high schools go into the Senior High Schools to prepare for Ordinary or Higher Certificates and the remainder go into Junior High Schools catering for the pupils only to the end of compulsory education.

Those at the Senior High Schools intending to proceed to University will spend five years before writing the Scottish Higher Certificate of Education examinations. This is the same period as is spent in South African High Schools. Physics as a separate subject is the most popular choice with chemistry and biology enjoying an equal following. Pupils who take two sciences have the opportunity at the end of the five year period of writing either two separate papers in their chosen fields or a combined paper known as Higher Science and embracing three sections (physics, chemistry, biology) of which two sections are to be answered.

Much has been written about the Nuffield Science Teaching Projects but little has been said of the Scottish Alternative syllabuses in the sciences, though these preceded the Nuffield schemes by several years. One of the architects of the Scottish approach was the late Donald McGill, who was later invited to lead the Nuffield Physics Project. Unfortunately he died soon after assuming this post.

Fundamentals of the new philosophies

The main reforms sought in the new approaches to physics and chemistry are the revision of content and method of presentation.

In the first it was necessary to remove from the old traditional syllabuses some of the matter to make way for the modern subject matter which would give to physics and chemistry a direct link with the problems and discoveries of the present day.

In Physics the reform of the content of the course is obtained by first removing the artificial compartments into which traditional physics was divided. The second was to consider only fundamental concepts which permeate all physics. Newtonian mechanics, energy flow and energy conversions, waves, electromagnetism and atomic physics became the keystones of the new edifice. Whereas the traditional syllabus concentrated on static situations, the new approach pays more attention to the dynamics of the content.

The introduction of atomic physics into a school course has brought howls of horror from the traditionalists who ask how it is possible to introduce the experimental work to support the theory. The new courses have shown that it is not necessary to hamstring pupil progress by a slavish insistence that everything which is acquired in the way of knowledge must be demonstrable as true. In any case, there is certainty that the traditional methods and content did not rest on any firm grounds of fully substantiated development, scientific evidence and deduction. The architects of the new edifice have not hesitated to use the 'blackbox' technique whereby they hasten the completion of the building.

The spirit of the new approach is that of Armstrong, not the complete heuristic approach, but an approach which eliminates detail which tends to obscure, works more from first principles and cultivates among the pupils a critical faculty. In the laboratory this means that the pupil's capacity to use scientific methods is of more importance than his ability to carry out a series of recipe instructions which enable him to 'verify' the value of a constant.

In the new philosophy the pupil is presented with a problem and he is encouraged to carry out investigations for himself within the limits of the laboratory facilities and his own abilities. The teacher is a guide and counsellor who keeps the experiments within the level of the pupil ability and maturity. The teacher becomes a guide rather than an instructor.

It must not be thought that accuracy has been abandoned. There is a place for detailed determination of one or two physical constants which will be done as accurately as facilities allow. This is done, however, motivated by the idea of 'seeing how it is done' rather than actually to determine the value — tables are available if we merely want the value of a constant.

What is being encouraged in the new philosophy is a transfer from the didactic to the exploratory and operational methods. The P.S.S.C. work in this direction is of particular interest and should be studied by all who are interested in improving teaching techniques in Physics. The pupil operates with concepts instead of trying to define them as was required in the past. The traditional insistence on definitions often made confusion worse confounded, when the aim was to simplify things. This attitude of demanding a definition and a law before using a concept was particularly strong in the older conservative teachers. The best teachers have been aware of the defects of the traditional teaching and some few have had the courage to use the new philosophies at the risk of the examination paper placing their pupils at disadvantage. Indeed, it is from the experiences of these courageous teachers that much of the good in the new approaches has come.

The problems in chemistry were similar to those in physics — what to leave out of the old and how to link the new. It was decided that the three fundamental concepts of chemistry are energetics, bonding and atomic structure. The traditionalist would be certain that these advanced concepts could never be presented successfully to schoolboys and girls.

Energy, bonding and atomic structure are closely linked since bonding depends on energy, and atomic structure must satisfy the requirements of the energy considerations.

The broad outline of the approach in chemistry may be said to be: allow the pupils to experience chemical change. From this experience they will discover that chemical change is linked with energy changes.

The burning of magnesium is no longer just a spectacular burst of flame with the production of a white ash: there are energy changes to be considered. It is important in the early stages not to attempt a formal definition of energy, rather let the concept develop through the numerous examples encountered at the chemical bench. All pupils have some elementary concept of energy upon which to build.

In both the physics and the chemistry courses emphasis is laid on the particular nature of matter and the explanation of phenomena in terms of this concept. No time is wasted, however, on a study of Daltonian atomic theory or attempts at experimental determination of laws of constant or multiple proportions. Rather these 'laws' are allowed to flow out of the particular nature concept. At best the experimental results at school level are but crude approximations.

In the traditional approach a great deal of time was spent in determinations of equivalent masses. In the new philosophy quantitative chemistry is approached from a consideration of the gram-atom, gram-formula, and the mole. Great care is taken to avoid any idea that the Avogadro number is limited to the number of atoms, or molecules, — the type of particle is immaterial. It is interesting to note that despite the first appearance of 'mole' in South African syllabuses equivalent mass is still retained. Possibly this is to justify the determination of atomic masses from equivalent mass valency considerations. This despite the fact that the experimental results in the hands of school pupils are so unrealistic. Recognizing this difficulty the planners of the new philosophies have not hesitated to introduce the pupils to the mass spectometer at least in name and outline.

In chemistry the use of the 'model' concept is widespread. The development of the model of the atom from the simple spherical particle to the nucleus plus electron clouds presents a pretty training in the development of models to suit new facts and theories. In this way even those who do not proceed beyond school science build up a vocabulary of atomic terms and concepts which will enable them to read with understanding news of events in their world.

By the elimination of much of the historical approach the organizers have been able to include much of new material close to the frontiers of present scientific knowledge and achievement. Again this is in keeping with the desire to bring the teaching matter into line with everyday happenings. They have introduced some non-academic organic chemistry which gives at least some indication of the vast field of the organic chemical industry which impinges on our life from all angles.

Perhaps the policy statement of the Association for Science Education issued in 1961 most adequately sums up the new philosophy.

"The work should be firmly rooted in the kind of practical experience which uses observation and experiment as a means of discovery, and for solving problems rather than for mere 'verification' of previously stated facts. Practical work leading to the formulation and testing of hypotheses is to be encouraged. Throughout the course opportunities should be taken to relate facts and principles to everyday life and experience; judicious digression to discuss matters of topical interest can be most valuable if made at the appropriate time.

We must develop a new system of school science teaching. We cannot do this by teaching only science of generations long past, though that has its place. Present syllabuses are out of date. To remedy this we have included in our syllabuses much of what has been discovered in the last sixty years and have excluded much which in that time lost interest and significance, and we have regrouped the subject matter as a whole in an attempt to show how science is regarded today."

Those who have read the preamble to the Common Basic Syllabus will find a strong similarity with the views expressed above.

The new philosophies have introduced a concentric approach in which concepts are introduced in a primitive and almost casual way at the beginning of the courses. Little by little the concepts are refined and the child reaches his own understanding at each level. This has the added advantage that it emphasizes that science is not so much an established body of truth, but rather a continued pursuit of truth, a movement to better and better models and analogues.

It is one thing to provide new philosophies and build syllabuses around those philosophies. It is quite a different matter to get them running smoothly in schools.

Implementing the New Philosophies

1. *The Scottish Education Department Alternative syllabuses.*

In 1962 the Alternative syllabuses of the S.E.D. in Physics, Chemistry and Biology were introduced in *a dozen selected trial schools.* The old traditional syllabuses ran concurrently in the other schools.

The approach in the Alternative syllabuses being so different from traditional teaching, a series of booklets were issued side by side with the syllabuses. News letters were also sent out from time to time dealing with specific sections of the work. Inspectors, University lecturers, Training College lecturers and teachers all took part in the preparation of these handbooks and news letters.

Intensive series of refresher or adaptation courses were arranged. A great part in the presentation of refresher courses was played by the Training Colleges, not only in science subjects but in other subjects also. At some training colleges as many as four nights a week throughout the school year were set aside for lectures designed to assist the teacher in the classrooms.

Area committees were established by the various educational authorities and these brought teachers together for meetings and discussion. Travelling expenses for these meetings were met by the educational authorities.

In many centres workshop facilities with trained technicians were established. Here teachers were able to meet and make apparatus or see new apparatus.

In Edinburgh a Scottish Schools Equipment Research Centre was established. Firms send equipment for assessment, teachers send ideas and prototypes are made. Bulletins are issued regularly in which the latest equipment is reviewed and articles of interest to the teacher in the classroom are published. These articles are directly linked to the teaching of the syllabus and do not profess to supply elaborate philosophical treatment of background material which is left to the various scientific publications.

New approaches on the experimental basis demand increasing quantities of apparatus and all the educational authorities made sure that the necessary apparatus was available in sufficient quantities for the approach to be followed.

Increased pupil activity in experimental approaches makes demands on laboratory accommodation. In Scotland, even with the old traditional syllabuses, the laboratory ration was *one laboratory for 100 pupils*. This ideal had almost been achieved throughout the schools so that there was no difficulty in implementing the philosophies in so far as physical requirements were concerned.

The increased quantity of apparatus needed and the increased pupil activity makes greater demands on the teacher unless some less academically qualified personnel is provided to handle the apparatus side. In Scotland the ration for technical assistance is *one senior technician, one other qualified technician and one or two apprentice technicians for each five laboratories.*

I doubt if any South African Educational Authority has achieved a corresponding laboratory ration to that of Scotland. As far as I am aware, only one South African Education Authority provides any technical assistants in schools. Even these are not qualified by any specialized training. Shortage of manpower suggests that we could not hope to fill technicians' posts in schools unless non-Europeans are used and unless training institutions provide courses for school technicians as is done in Britain.

It is interesting to note that although the Scottish Education Department laid down that all schools would be compelled to offer the Alternative syllabus in the examinations of 1971, by 1966 96% of all Scottish High Schools had elected to present pupils for examination in the Scottish Higher Certificate Examinations on the alternative syllabus.

2. *The Nuffield Science Teaching Project.*

In 1962, largely as a result of approaches made by the A.S.E., the Nuffield Foundation made available funds amounting to almost £1,000,000 for research and a further £500,000 to meet publication costs.

The initial programme of the Foundation envisaged a five year programme of science and mathematics for the 11-16 year old pupils in Grammar Schools and the academic streams in the Secondary Modern Schools — the same approximate 25% of the secondary pupils as was catered for in Scotland. Time showed that further researches were necessary for the primary schools and for pupils outside the 25% mentioned and also for those proceeding to A-level studies for University Entrance qualifications. This latter research is only now getting into its stride and little has been published as yet.

Donald McGill, the architect of much of the Scottish development, was appointed leader of the physics project. After his unfortunate death Professor Eric Rogers of *Physics for the Enquiring Mind* fame, was appointed leader.

The first committee agreed that the course should be designed to bring the student into contact with contemporary science so that he would become an understanding citizen, or be able to go forward to further studies in the sciences in more specialized fields. To meet this need it was intended that the course should develop an understanding of the manner in which theories develop and to ensure that the pupil leaving school fully realized that there were still answers to be sought and found, and that science was not as yet a completely developed and rounded off subject.

The traditional syllabuses were examined critically to determine to what extent the various sections contributed to the further development of scientific thought. Such traditional subjects as Archimedes, geometric optics, and much of the traditional experimental determinations of data, e.g. specific heats, and focal lengths were eliminated or relegated to the background to make way for more modern material which would contribute to the fulfilment of their ideals.

The course has been built round concepts of energy, molecular properties of matter, kinetic theory, waves and optics, fields, dynamics and quantum phenomena.

At first sight this seems an incredible task when viewed against the age groups for whom it was intended but the concentric approach enabled the subject matter to be presented at a level of sophistication which the pupil could assimilate at each stage of development.

Examining bodies were approached with the new ideas to make sure that they would set examinations in keeping with both the subject matter and the spirit of the courses and Educational Authorities were asked to allow schools to work through the subject matter on a voluntary basis. Both requests met with approval and a number of schools expressed their interest.

Although the course covers five years it was felt that the need for reform was so urgent that a short circuiting of the time for a complete coverage in each school would be necessary. Some schools were asked to start at the first year of the course and others to pick up the threads at the third year level. In all 100 teachers and 4000 pupils were involved in the preliminary studies. Each week information from these experimental schools was fed back to the headquarters teams who analysed the findings of the teachers in the classrooms. As a result a second version of the scheme was prepared and subjected to test. A third, and for the time being, a final version was prepared in June 1966. These final versions were published in printed form and available for teachers. The research team steadfastly set themselves against producing a formal textbook for the use of pupils, though question books were made available.

The fundamental philosophy follows that of the A.S.E. and the Scottish scheme — namely place the pupil in an environment where he experiences science. The pupil is encouraged to make suggested explanations and helped to follow up his suggestions. The programme strives to build on the natural curiosity of children of the age group under consideration, it encourages them to think for themselves, to seek for evidence and to use their own judgement.

Visits to laboratories, talks with pupils and with teachers convinces the student that the philosophies are producing pupils who are gaining a measure of scientific understanding which exceeds that of the products of the traditional approach and certainly in excess of what we have been achieving in our own traditional teaching. At the same time we must keep in mind that the pupils at the end of the five years have been further reduced by the drop out after two years of pupils who have not shown the aptitude or interest needed for further studies in the sciences. Compare this with the students under our system, where, once started, they continue through to the bitter end (sometimes very bitter) the science they started with.

As in Scotland, numerous refresher courses, series of lectures and local committee action were undertaken to familiarize teachers with both the subject matter and the approaches to be used. The most ambitious programme was the establishment of full time extensive courses at training colleges. These courses ran for the full term of approximately 10 weeks. These courses were sponsored by the Ministry of Education. The filling of the courses was by nomination by the Local Education Authorities.

The standard of the work presented at these courses was high and teachers were able to see the new approaches at work in neighbouring schools . Initially the courses were intended for Senior Teachers who would then go back to their own areas and spread the word. Unfortunately, no provision was made for reimbursing teachers for the additional expense incurred by having to maintain a home and family in one centre whilst attending the course in another centre. In addition, the difficulties in providing adequate substitutes for the teachers whilst on course made Headmasters reluctant to nominate their best teachers or indeed any teacher for these courses.

The Nuffield teachers redesigned much of the old apparatus and thought up some new pieces of apparatus for the new work. Manufacturers co-operated in the provision of much prototype apparatus for use during the trial periods. Commercial firms put their film making units at the disposal of the organizers and many films aimed at teacher training were produced. These films are now available in South Africa. Television programmes were also devized and proved helpful in disseminating information about the new approaches. 16mm Films of the television material have also been made and are being used in various parts of the world in teacher training sessions.

The Chemistry committee found much the same problems as the physics committee, namely that there was material in the traditional study of chemistry which made little contribution to further studies. The committee finally decided to introduce two thoughts in the first two years —"examining material" to provide a background of chemical reactions and "examining ideas". In the second stage the pupil was to be encouraged to think about reasons for chemical behaviour. These two sections were to cover one year each (though some schools found that with brighter pupils they could manage it all in one year). The last three years of the five year course were to be devoted to a number of "options" each providing extensive studies of particular aspects of chemistry. These options apply and extend the general principles encountered in the first two years. The resulting depth of study was to be deeper than that achieved in the traditional approach, but naturally on a narrower front.

The Nuffield schemes have not received the same degree of universal acceptance as has the Scottish Alternative Syllabus. Perhaps the reason lies in the fact that the Scottish Higher Certificate was then the end of secondary education whereas in Britain after the O-level (covered by the Nuffield Scheme) further study is required for A-levels necessary for University Entrance. The Nuffield Project, as already stated, is only now busy on an A-level programme. Schools who have adopted the Nuffield scheme in its entirety have had to switch to more traditional syllabuses for the A-levels. Masters, however, do claim that their pupils are not handicapped when the change is made.

Even those most closely attached to the Nuffield Research team do not claim that everyone should adopt the Nuffield scheme in its entirety, but all are adamant that the basic philosophy should be the guiding factor in both syllabus construction and teaching approach.

In our South African system most pupils in our High Schools have three years of General Science embracing physics, chemistry, botany and zoology. The elaborations supplied by each examining body make it quite clear that the experimental and investigatory approach advocated and practised in Britain has been accepted. Initial reports indicate that the approach has been welcomed by teachers and pupils.

It must be noted, however, that the time available for General Science in our schools is less than the time available for a similar amount of syllabus material in schools in Britain.

The Common Basic Syllabus for Physical Science is now in all our Std. 9 classes. Examination of the syllabus in action suggests that the amount of subject matter included in the syllabus is more than can be handled on the experimental basis advocated overseas in both the Scottish approach and the Nuffield approach. Whereas in Scotland five periods per week are allocated to each of physics and chemistry we in South Africa are able to allow only six periods per week to cover almost as much as is contained in the two syllabuses of the Scottish educational system.

Differentiation is not universal in South Africa and where there is differentiation the percentage of pupils going forward into the advanced grade stream is much greater than the 25% of pupils in Britain going forward to equivalent studies. Add to this the fact that our pupils take physics and chemistry as a combined science in about the same number of periods as is allocated to each branch in Britain and also that the amount of work included in our syllabus is almost the same as that included in the two syllabuses for physics and chemistry in Britain and it will be seen that the task facing the physical science teacher and student in South Africa is a formidable one.

It is noted that overseas projects were tried out in trial schools before being presented for universal consideration. In Scotland there is now universal acceptance of the new syllabuses and approach but the acceptance of the Nuffield schemes is limited as is the case with the P.S.S.C. Chem Studies and Chemical Bond Approach in the U.S.A.

There is no doubt that the compilers of the Common Basic Syllabuses were influenced by what was being achieved overseas. There is also no doubt that a close watch must be kept on the progress of the syllabuses in our teaching situation and that much thought must be given to ways and means of providing teachers with the tools both physical and academic with which to do their difficult task. Constant review and revision where necessary will also need to be undertaken if we are to achieve the aims and ideals laid down or implied in the preamble to the Common Basic Syllabus.