science education in the future

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If one were to extrapolate into the future from the situation over the past two or three decades with respect to science education in the schools, the picture which emerges could only be described as bleak. This is because all the evidence reveals a marked deterioration in the teaching of science. Therefore, before looking towards the future, it would be advantageous to study the past and consider what has gone wrong. In education, South Africa has problems of its own, largely because, in this country, education is a sensitive political area and decisions are often taken which are educationally unwise but politically expedient. Nevertheless, the problems of science education are international, and although in some countries they may not be as pressing as in others, in general, they have much in common.

Before the First World War, science teaching in the schools was barely tolerated. The physics component was considered necessary as was understandable in a world enjoying the fruits of a mechanical age. But chemistry was considered to be the domain of cranks and eccentrics. Chemistry's early history of development, first promoted by alchemists and then by gifted amateurs, had in the previous century been followed by the most sensational advances and it had become a most respected branch of science. Nevertheless, in the schools, the nickname "stinks" still set the tone for attitudes towards it. The teacher of classics still looked upon the teacher of science with some contempt.

In the interwar period, the attitudes towards science changed, because it was becoming increasingly obvious that we were living in an age in which the effects of scientific advances were affecting everybody and could not be ignored. It was, therefore, essential that science teaching should be given adequate weight in a school curriculum. The physics, as then taught, differed little from that taught in previous decades, and chemistry consisted largely of a few elementary laws and the preparation and properties of a few simple substances. It was not very inspiring, nor particularly useful, but, fortunately, it was still considered appropriate that there should be some associated laboratory work so the pupils did not resent the subject, and some even enjoyed it.

The Second World War introduced a completely new attitude to science. The sensational developments of the period, the discovery of new materials and drugs, the achievements in electronics and radar followed by the realisation that the enormous stores of energy in the nuclei of atoms were able to be tapped, alerted the politicians to the realisation that those nations who were most advanced scientifically were most likely to prosper. Science education moved upwards in priority. The question was soon asked, very appropriately: Were we teaching science in the best way possible and were we doing so at all levels? The answer was that we were clearly not doing so, and this reflected opinion, not only in South Africa but throughout the industrialised world. What was wrong? Before we can project into the future, it is necessary to consider this problem and the solutions which were proposed for it.

In most of this article, more emphasis will be given to the problems affecting chemistry teaching than to those affecting physics teaching. This is because, unlike that of chemistry, the teaching of physics at the school level has not changed very much over the years. The revolution in physics thinking which occurred in the early part of this century had little bearing on the subject matter which could be taught in schools. Chemistry teaching, however, presented a far greater problem. This is because the science of chemistry was subjected to two important intellectual pressures. In the first place the body of knowledge in chemistry had begun to expand at a phenomenal and accelerating rate and is still doing so. This soon produced the problem of selection as to what to teach and what to omit. The second pressure arose because chemistry, suddenly and dramatically, changed from a largely descriptive science to one which was very logical and much of which could be explained in mathematical language. There was now an understanding of the forces operating in molecules and being exercised when they changed, and though there is still argument as to the meaning and behaviour of these forces, it became possible to teach chemistry on a much more logical basis. For that reason, there was considerable discussion during the post war period on how chemistry should be taught, both in schools and in the universities. Most scientists were united on one matter. The old syllabus based upon preparation and properties of an arbitrarily selected group of substances was outmoded, dull, irrelevant and should be scrapped. In its place, there should be a new approach based upon the now well-established electronic theories of the chemical bond. I think it is realistic to say that this new approach has been very successful at the university level and has succeeded in making chemistry a much more interesting subject to study. Unfortunately, it was simultaneously felt that a similar change in approach should be made at the school level. One approach, not attempted in South Africa, was to use chemistry as a means for introducing the scientific method of reasoning. Experiments were carried out by the pupils and they were encouraged to make the consequential logical deductions. As this method is based on experiment, it may still prove to be educationally sound, but it is still being assessed. However, in South Africa, with inadequate preliminary study, a more theoretical method was adopted. This has proved to be a disater, and it is interesting to note how this came about.

The initiative for change was taken by the South African Chemical Institute which set up a committee to review the syllabus in chemistry for those who were studying "Chemistry" as a singular subject, not the chemistry component of the subject "Physical Science". Because it was highly probable that a pupil who selected the much more demanding subject of Chemistry in preference to Physical Science would want to continue that subject at a university, the thinking of the committee was that the syllabus should provide a suitable introduction for that subject at a university. For that reason, it proposed a syllabus which emphasised bonding theory and physical chemistry and which was essentially a very theoretical approach to chemistry. However, the committee failed to take account of two important considerations.

The first was that unless the teachers themselves were completely au fait with the latest theories and understood all the nuances implicit in them it was almost a certainty that they would not be able to explain the subject properly to the pupils. It was thought that this problem could be overcome by the universities providing refresher classes for science teachers, and, indeed, most universities went to considerable trouble to offer such classes. Apart from that of a handful of dedicated teachers, however, the response was poor, and this can be blamed upon the Department of Education which failed to offer sufficient incentive for teachers to improve their background in chemistry.

The second consideration that was ignored was that of the maturity of the pupils. The syllabus that was adopted was highly abstract. However, it seems to be a fact that abstract thinking of a meaningful kind only becomes possible with advancing intellectual maturity, and, in fact, many people never acquire it properly at all. For the pupil of 15 to 17 years old, the kind of abstract thinking needed to comprehend chemical bonding in a meaningful way even in the simplest terms is possible only in the case of a few of the very gifted. For the others, there is little or no understanding which means that the schools simply memorise certain definitions, and the whole experience becomes futile. Not only do the students not understand the concepts, they often acquire misconceptions which become very difficult to correct at the university level. Above all, they find the syllabus tedious and dull because they do not understand it.

However, this syllabus was accepted and as only a handful of scholars took the subject "chemistry" not very much harm was done. Unfortunately there then occurred one of those decisions which, in retrospect, reveal such crass stupidity as to be almost incomprehensible. The Joint Matriculation Board decided to use virtually the same syllabus, somewhat shortened, but in essence based on a similar approach for the chemical component of the Physical Science syllabus. The effect of this has been a major disaster whose repercussions could eventually affect the economic growth of South Africa. Not only was there only a handful of teachers suitably qualified to teach so sophisticated a subject, but the syllabus was far too long. Most teachers, more at home in any case in physics teaching, sacrificed chemistry time to physics, hoping, correctly as it turned out, that a fair knowledge of physics would enable their pupils to pass even if they knew little chemistry. For that reason, many students have arrived at university with excellent grades in Physical Science, but virtually no knowledge of even the most elementary chemistry. University teachers of chemistry have, therefore, no option but to teach chemistry assuming no previous knowledge on the part of the students.

But there is an even more serious consequence. Chemistry, because of the nature of the subject, should be taught in close association with laboratory exercises even if only at the most elementary level. However, school teachers, with a few laudable exceptions have been reluctant to develop laboratory classes. There are several reasons for this. Laboratory exercises are time-consuming to prepare and dismantle, but the Department of Education seems strangely reluctant to provide the necessary technical assistance to help in this work. The short-sighted policy of the Department of Education in this respect cannot be too strongly criticised. Some teachers, too, have not enough experience in chemistry to design and supervise laboratory exercises. Many are frankly too scared to organise experiments which in unskilled hands could be dangerous. At one time the excuse was used that there was no proper laboratory equipment but this is no longer the case. Departments of Education have provided adequate funds to procure the necessary equipment and many schools have excellent laboratory facilities which are never used. Most teachers use the excuse that, because of the inordinate length of the syllabus, the time allocated to laboratory work could be better employed in teaching theory. The unhappy situation has now developed in which the majority of schools teach chemistry purely as a theoretical subject and the pupils have no contact whatsoever with the simplest of laboratory equipment. Most, when they get to university, have not previously seen a burette or a pipette and do not know how to light a bunsen burner. The consequence of this neglect of laboratory work is deplorable. Without practical work, chemistry can become a dull and uninspiring subject. Thus the contact with the subject at school produces no incentive to encourage the pupils to consider making a career in chemistry. On the contrary, it does just the opposite. Those who have the intellectual ability and might have chosen to study chemistry for a profession are, in fact, put off the subject. The sharp fall in the enrolment of chemistry students can, without question, be blamed on the syllabus and its effect on the teaching of chemistry in schools. It is misleading to blame the shortage of chemistry graduates on the same factors as pertain overseas. In Britain and in the USA there had been overproduction of chemists so immediately that there was a downturn in the economy, the shortage of jobs combined with considerable retrenchment created a situation where many chemists were unemployed with the consequence that chemistry became an unattractive career and still remains so. In South Africa, however, this has never been the case for the past 30 years. There has always been a shortage of chemists and this was, in fact, overcome by importation from overseas. It is this shortfall of chemists which is mainly responsible for the shortage of qualified science teachers. Of recent years, the unattractiveness of a chemical career in South Africa is due to the misleading impression of chemistry created in the schools, and this is going to cost South Africa dearly. This is because there is no longer the reservoir overseas from which to import chemists. South Africa has no option but to produce its own chemists. This is why so much thought has to be given as to what happens at the school level. This is the excuse for what must appear to be an overlengthy preamble to a discussion of science education in the future.

Clearly the school science should once again be reviewed and this should be done sensibly after consideration of what such a syllabus should be expected to achieve. The question should even be raised as to whether it is suitable and expedient to teach it at school level at all. To that question there can be only one answer. If, as is generally asserted, the aim of school education is to prepare the youth for a full and useful life, then, in a world which relies upon scientific progress, some knowledge , however elementary, of scientific fundamentals is essential. The basic principles taught in physics need little modification. What are the basic principles which should be taught in the chemistry component?

One of the problems of the South African educational system is that there is one terminal examination which has to serve a dual function. Not only is it supposed to indicate that a sufficient standard of education has been reached to justify a school leaving certificate, but the same examination, with some restraints, is expected to serve as an entrance examination for university. When dealing with a subject like chemistry it is clearly impossible to reconcile these two objectives. For that reason it would be better and more reasonable if the school leaving objectives were attained and the university entrance level ignored. In other words, those aspects of chemistry which the man in the street needs to know for his every-day living should be emphasised. Included amongst these would be water, acids and bases, salts, pH, metals, common gases, electrolysis, common materials such as glass and polymers, fuels, foods, swimming pool chemicals, fertilisers. These should all be treated as accurately as possible, introducing essential concepts, but always emphasising the practical angle. The properties and uses of oxygen, for example, can be explained at that level without resorting to molecular orbital theory. In all cases possible, these studies should be closely linked with some practical work. To ensure this, it is essential that the Joint Matriculation Board insists upon a laboratory mark for each student, given either as a class mark or by examination. In designing the syllabus, it is essential that it be made interesting and exciting. One way to achieve this is by the introduction of some environmental problems, thus relating to some of the pressing problems of society. Similarly, the laws of thermodynamics can be illustrated by reference to energy problems, and the concepts of photochemistry, which can be given in a simple way, can be illustrated not only by reference to photosynthesis but also to the ozone controversy and smog production. In this way chemistry can be shown to be dynamic and relevant.

Within such a framework, it is possible to devise a self consistent syllabus which will not only be informative and interesting but which could be used to introduce concepts forming a sound basis for entry into introductory courses at university. Equally important, there must be quantitative problems to give the scholars exercises in clear thinking and the necessity for exact measurement. To sum up, the course must be interesting, informative, challenging and relevant. As it would be impossible to cover more than a very small fraction of existing chemical knowledge, it would not be important which areas are covered and the choice should be decided by the objectives of the course.

For many years to come there will be an acute shortage of qualified science teachers. This cannot be overcome by the use of mechanical teaching aids such as programmed learning because chemistry must be more than an accumulation of facts and because no computer can replace a demonstrator in the laboratory. The syllabus, therefore, should be one which could be handled by a teacher who has not been too deeply steeped in the sophistications of the subject. It should be descriptive and the treatment should be based on atomic and electronic concepts, though these need be treated in a very elementary fashion.

However, serious consideration should be given to another approach in the teaching of chemistry. This is by the introduction of the fundamental concepts in a syllabus which is essentially that of the History of Chemistry. The History of Chemistry, itself a fascinating subject closely integrated with the development of modern society, is largely descriptive. Nevertheless, the conceptual understanding of chemistry develops as the subject unfolds culminating in the excitement generated by the development of atomic energy. Provided this syllabus is combined with some laboratory work as well as lecture demonstrations, it should be possible to achieve the dual objective of introducing some of the chemistry necessary for the lay-man as well as creating some interest for the few who might want to embark on a career in chemistry. Such an approach would have the advantage of showing how the scientific method works. This would be of much more value than a poorly presented description of atomic or molecular orbital theory, and would be much more within the capabilities of both teacher and scholar.

It cannot be emphasised sufficiently strongly that whatever the subject matter of the school syllabus for science, the chemistry component must include some laboratory work. Any syllabus that neglects this is valueless as an introduction to science and its dullness may deter students, able enough, from choosing a career in science. It might even go further and put them off from entering the applied sciences such as engineering and medicine. It is true that at the moment these areas still attract enough students to meet the demand, but this is largely because of financial considerations. At a time when socialist theory is in the ascendency and more and more professionals become state employees enmeshed in bureaucratic chains, the financial inducements may no longer apply in the future and the school classroom will have to be used to encourage interests in the applied as well as the pure sciences. The syllabus will play its part in this.

Whatever steps may be taken to reconstruct the science syllabus in the schools, these will not solve the underlying problem that our educational system is not succeeding as well as it might in its efforts to prepare the young for the future. For that reason, it is appropriate to review the whole educational system, assess what is wrong and offer some alternatives.

Not only in South Africa, but throughout the world, there is growing criticism at the quality of the product of the schools. There are complaints about illiteracy and inability to use language to communicate, an inability to make the simplest numerical computations, a lack of critical assessment, a sloppiness of attitudes and a general indifference to acquiring knowledge. It is facile, and misleading to blame this on poor teaching. In an age where most professions and trades earn financial rewards far greater than are operative in the teaching profession, anyone who embarks on a teaching career must be dedicated and dedicated teachers are usually good teachers. There must, therefore, be something else responsible for this deterioration in education. In this connection, not enough consideration has been given to the growth of knowledge, and its complexity, and the minimum requirement for good and participating citizenship. There can be no question that the average man needs to know more than his predecessors if he is to lead a full and useful life, and most of this knowledge must be obtained in his school years. But the time spent at school has not changed significantly for generations. So more and more material has to be crammed into these formative years. The consequence is inevitable. The subject matter is diluted, it becomes more superficial and not as much is retained. In other words, we are short-changing the pupils and the deterioration is remarked on by business, by universities and by the public service. Those who imagine that the computer can be used to overcome this deficiency are making a bad mistake. As is already being found, the computer cannot replace an intelligent human being. It can only assist him. Therefore, if our civilisation is to continue advancing, the educational system must come under review.

The first task must be to determine as reasonably as possible what is the minimum level of knowledge needed for someone who is to play a useful role as a citizen in a scientifically orientated world, who is able to exercise his vote sensibly and is able to communicate without ambiguity. We expect that level to be reached at the age of 17 or so in spite of the fact that it is always growing in extent. Should we not be thinking in terms of increasing the educational period, possibly by two years? After all, the expectation of life has increased enormously and, therefore, the number of years of working life. Would it be very unreasonable to use about two years of this for improved preparation?

The way to do this would be to establish two-year post matriculation colleges somewhat akin to the Junior Colleges in the United States. Their objectives should be to improve the level of knowledge for those who do not wish to proceed to University, and also to serve as an entrance college for universities. Only those who attain a sufficient standard at the Junior College would be permitted to proceed to a University. This should be part of the normal educational process, and eventually it is hopped that all who are capable will graduate from the Junior College before starting to work. Should we establish such colleges, the problems of science education would resolve themselves because we could then teach science at a time when the students are more receptive and it could also be taught at a more satisfactory level.

It will be argued that South Africa could not afford these extra colleges. I think it could. Part of the cost could be offset against the enormous waste of time, effort and resources caused by the high failure rates at the Universities, at a very expensive level of education. But we also have far too many universities, many of which are unable to meet the overseas standards of research typical of a good university. Only a few of the better ones should remain as universities and the others should be converted to Junior Colleges. These would then become feeder colleges for the universities, and for the colleges of Advanced Technical Education. By rationalising our educational efforts in this way, we would in the long run have a far better system, and one that is more economical.

The universities would then have an input of students who were much better prepared, the appalling first year failure rate would be reduced and the quality of graduates would improve. This would surely be a better situation than the alternative which is already manifesting itself and which would otherwise be inevitable. This is that the universities would be forced to take on more and more of the functions of the High School. There are many signs of this in the provision of pre-university classes, in the provision of special tutorial classes for the weaker students, and in the weakening of first year courses. Students appear in my department of chemistry who cannot use logarithms or do simple proportion. As chemistry cannot be taught without these prerequisites, we have to teach them. Increasingly courses in communication have to be provided for students who cannot compose simple essays or reports. As time goes on, more and more of this material appropriate to schools will have to be taught at University unless some alternative educational stage is provided. The growing pressure for higher education is imposing a burden on universities which are admitting students who are really not suitable for university studies. Nevertheless they apply for admission, because they feel, quite rightly, that they need something more than that which is provided by the schools. Junior Colleges would satisfy that need, and it could well be that, once they were established, a diploma from such a college would be much more highly prized than is the matriculation certificate which many of us are beginning to feel could well be considered to be an intellectual fraud.

At the Junior College level, it is important that Science should not be taught in the sophisticated way which is essential at University level, but should be based on the principles outlined earlier in this article as being appropriate for schools if the existing system in maintained. At the Junior College it could, however, be taught very much better by better qualified teachers and based on this the universities would be able to develop improved and more coherent courses in Physics and Chemistry.

There is another aspect that should be considered. Science, although it has been discussed as though it were only physics and chemistry is, of course, a much more widely spread discipline. A course in science could incorporate as well, in an integrated form, the biological and geological aspects of science. Geologists complain that scholars at school have no contact with geology and biologists complain about the erroneous impression created of biology as though it were a purely descriptive science. If a Junior College were part of the educational system, a course in Science should be a compulsory subject at the college, but it should be science and not only parts of science. For example, in a discussion of crystals and solids, some attention should be given to elementary mineralogy. In discussing solubility the weathering of rocks and formation of others could be included. In discussing surface tension, the connection now being revealed between surface tension and cytological behaviour could be part of the discussion. There are many such examples. In other words, the division of science into compartments should be replaced by better integration. This will require very careful preparation but it is in line with educational experiments at earlier levels in the schools.

Clearly some change is essential. To continue along the present lines can only end in disaster and the degradation of our education to unprecedented depths. The problem of science education cannot be solved in isolation by simply changing the syllabus. It can only be solved as part of a general new deal for education in South Africa. The first step in that direction would be the establishment of a **non-political** government commission set up to study the problems of education as a whole and not fragmented into sections such as schools, universities, technical colleges and so on. The matter is very urgent as education in South Africa does not compare well with that in many overseas countries. Educational neglect can prevent this country from achieving the greatness for which its history and geography gives promise. This would be a great pity.