BASIC COURSES IN CHEMISTRY

José D. Gómez-Ibáñez

Department of Chemistry, Hall-Atwater Laboratories, Wesleyan University, Middletown, Conn. 06457, USA

ABSTRACT

Reference is made to the content and philosophy of basic courses in chemistry. The contents should reflect what chemistry is today, its evolutionary growth and its expanding conceptual framework. Chemistry being an experimental science, its presentation should reflect the close interplay between observation, theory and experimentation. The usefulness of models should be emphasized, as well as their limitations.

No rigid outline for a course should be formulated inasmuch as any particular one is given in a social, cultural and economic 'context'. The importance of laboratory work and of the development of early habits of inquiry is emphasized. In large classes the laboratory may be the best vehicle to retain a close 'student–teacher' relationship.

In introducing the topic of this session I am particularly aware of the fact that much has been written and much has been said about it during the last few years. Contents of basic courses have been changed, emphasis shifted, tactics modified, but no rigid prescription has been given which satisfies all situations. It is not surprising for, after all, a course is always offered in a given context and in a given set of circumstances by a given teacher or teachers. And teaching is, as it should be, a very subjective thing. But none of us is set in his ways, and the great benefit of Symposia like the present one will result from the lively exchange of ideas and experiences. From such exchange we cannot help but find much good which can be adapted to our own style of teaching and to the circumstances of our teaching. On my part I will attempt, but briefly, to review or point out some of the problems associated with 'basic courses', and I confess that, while making some remarks, the context of Iberoamerica is in the back of my mind.

Generally speaking, a student entering the university in a Portuguese or Spanish-speaking country (and similarly in many others) is starting his speciality and has already been exposed, during his secondary school studies to mathematics, physics, chemistry and biology. How extensive and intensive that exposure has been varies from country to country. At any rate, the student taking the basic course at the university level has already chosen a career in chemistry or in some other science, pure or applied.

We will then talk about *a* basic course in chemistry for future chemists and scientists, disregarding at this time courses in chemistry (or in science) for non-scientists. This is, nevertheless, a very important problem to which, regardless of all that has been claimed and said, we have paid scant attention. On the other hand, we may keep in mind the possibility that *a* basic course effectively designed for the future scientist should also be effective in exciting a non-scientist who becomes interested in finding out what chemistry is all about.

The question is: What should be the content and the philosophy of such a course? Let me say first of all that I do not bring to you either a detailed outline or a ready answer. And also, and in reference to the theme of this session of the Symposium, that I do not think they should be determined by the number of students enrolled in the course. We have to assume that all our students have the same motivations and the same expectations and deserve the same contributions from us.

Both the content and the philosophy underlying basic courses in science have come under severe criticism and review during the last ten or twenty years, and I am afraid it will continue to be so because of the very nature of what we understand to be chemistry. The situation is not an unhealthy one. During the last twenty years chemistry has undergone a tremendous evolutionary growth, its domain expanding and its conceptual framework becoming more embracing. And it continues to do so. Chemistry has proved to be a very dynamic subject and continually challenges us to keep up with the chemistry of the moment. But once in a while we have to look back—not so frequently that we lose perspective, not so infrequently that we lose momentum—and examine what is the firm basis already attained, and what are the intriguing prospects.

One such examination was made last year at the Conference at Snowmass-at-Aspen, Colorado, and I would recommend at this time the reading of the report on 'The Structure of Chemistry' by the Committee under the chairmanship of Professors Hammond and Nyholm[1]. Paradoxically enough, it appears to be rather difficult to define our subject matter, and most definitions end up involving, in some way or another, the term being defined. The definition of the committee is no exception:

> 'Chemistry is the integrated study of the preparation, properties, structure and reactions of the chemical elements and their compounds, and of the systems that they form.'

But it is an acceptable one in that it 'delineates' the field of activity of the chemists. A very wide one to explore, since there seems to be no end to 'the systems that they form' and explains the ever-increasing areas of activity opening to the chemist.

Such activities have not been simply explorations. A science cannot develop without the formulation of abstractions and the use of models. In its growth, chemistry has gained a tremendous systematization. Thermodynamics, wave and statistical mechanics have provided a powerful theoretical framework and an 'explanation' to much of chemical phenomena. If we wish to add this aspect to our definition we may do so very consisely by quoting from Professor Hinshelwood[2].

> 'All that remains in the chemist's substratum of things seems to be geometry, motion and number.'

An appealing definition, which at least gives us an idea of the level of abstraction with which chemistry is involved.

But let us always keep in mind that chemistry is basically an experimental science and has retained a healthy empiricism. One important reason for the rapid growth and evolution of chemistry and its vitality is the result of the close interplay of observation, theory and experimentation. We should remember that the chemist, in carrying out the approximations he makes when applying theory, is guided as well by the empirical knowledge he is still accumulating. C. A. Coulson, a physical chemist who holds the Rouse Ball Professorship of Mathematics at Oxford, in the preface to his book *Valence* has stated[3]:

> 'Contrary to what sometimes is supposed, the theoretical chemist is not a mathematician thinking mathematically, but a chemist thinking chemically.'

From his abstractions, his models (so valuable particularly if they are simple) the chemist has to come back to the concrete realities of what can be observed.

All this has been said before, and I emphasize it now because I have a feeling that the content of basic courses has tended to swing between two extremes: the one has been primarily descriptive, the other leans heavily on 'principles'.

To counteract the array of facts, gadgetry and detailed industrial processes which crowded the textbook of thirty years ago, the early 'sixties saw the promotion of new introductory courses in the sciences attempting to reflect a more modern approach to the teaching of chemistry. Some of those texts have come lately under heavy criticism and have even been called 'dogmatic'. A well-known teacher of chemistry has described a particular textbook as being '. . . an array of "proven theories"'[4]. And the same critic has stated that '[in general] . . . these courses and other curricular attempts to improve elementary science courses in effect have alienated many students from science'. This is perhaps an overly severe indictment, since there are undoubtedly other factors contributing to the decreasing enrolments in the sciences, and these are of a social and psychological nature.

NEED FOR A BALANCED APPROACH

I am not joining in the controversy. But I am advocating a balanced approach because I am convinced that, if we are to convey to our students a real feeling for what chemistry *is*, we have to bring out and emphasize that interplay between the empirical and the abstraction, always pointing out the context and circumstances under which the abstraction is made. More recent directions in which the teaching of chemistry seems to be moving are encouraging ones.

Being more explicit than 'Geometry, motion and number', we can say that structure and function; energy and the dynamics of transformation; equilibrium—are the basic themes of chemistry, all of them embracing and absorbing the classical subdivisions. If we can show how the empirical facts have led to the concept, or model, and this in turn to further experimentation and more facts, how intuition can be useful, we will have accomplished something. I am not advocating an 'historical approach' or 'case study', often leading to boring repetition and to the temptation of a 'final' answer. For, any answer always brings new questions. Thus, if the arbitrary introduction of quantum numbers is made unnecessary when using the Schroedinger equation, or if the Pauli exclusion principle (for which there is no theoretical foundation) can be used to describe the distribution of electrons, neither answers the final question: What is matter? They make the mystery 'deeper'.

For the essence of science is a continuous quest, and the habit of inquiry must be started early. Laboratory work is essential for the development of this capacity, and more effectively so when combined to an early exposure to research. Some may say that the 'techniques' must be learned first, but one can also argue that certain techniques may be better appreciated and more meaningful while carried out in the pursuit of an objective. In either case we must insist that the question for which an answer is sought be clearly formulated. And I do not need to point out here the value the example of our own scientific activities may have on our students.

Another reason for the vitality shown by present-day chemistry is the way in which its methods and concepts have been extended to the elucidation of problems outside its own 'classical domain', to overlapping fields such as Molecular Biology, Earth and Space Sciences, ... these rapidly developing and exciting fields to which a 'chemical' approach has made important contributions are bound to provoke the curiosity of the student, always interested in bringing his experience to the fore and intrigued by the unknown. There should be plenty of occasions in a basic course to discuss some of these aspects of chemistry and, more important, to point out unsolved problems, or possible problems. Are those problems and aspects indeed going to contribute to a new structuration of chemistry?

I may caution here about the expectation that every one of those aspects or problems which may be touched upon is going to bring 'excitement' to the whole class. And I will advise the need for some 'expertise' in each case which can bring real feeling for the topic and make it understandable. I know of one instance in which active researchers in the appropriate field have been invited on occasion to address the class. The results have been quite successful.

I feel there is no single answer on how to accomplish all of this. Given the basic ingredients and basic philosophy, the structure and organization of the course will be determined in each case by the local circumstances, the resources, the economic means and by the availability of manpower. What may succeed in one place may not necessarily be the answer to the problems confronting another. In this respect I have often been surprised at the speed with which many adopt materials and approaches which are still at the experimental stage.

Take for instance the matter of level of the basic course. In some instances the level has been dictated by what is referred to as the 'standards of a university offering' disregarding the fact that locally there may exist a gap between the preparation of the incoming student and the demands of the first-year course. The instances may have been few but also may have accounted for high mortality rates. Since no country can afford the luxury of discarding any potential talent, the university has the obligation to contribute to the upgrading of education at all levels, and must do so if it is to fulfil its purpose. If a university does not have adequate manpower, equipment and resources, and cannot afford the cost, the hard work and ingenuity of the teacher must come into play.

CHEMISTRY CAN CONTRIBUTE TO LIFE

There is another fact I have not mentioned before. Science is an integral part of our culture but it has been accused of remaining aloof to a number of the problems of our times. In fact it has been accused, science or technology, it does not matter which, of being the cause of some of the problems we face today. Rather than take a defensive position with regard to this accusation we need to make a positive thrust and indicate how chemistry may contribute to the solution of some of those problems, and show honestly how it may have contributed to the problem, mostly not intentionally, but because of its intrinsic momentum. This is a grand opportunity to use as illustrations those problems most directly confronted by the students in their local environment, be it pollution, hunger, the fight against disease or the best use of the locally available resources. There is the experience gained from diverse attempts, information available from different sources, and great opportunities for meaningful experimentation. Some of it will result from this Symposium. I have, at this time and place, only one suggestion. It is quite common in many places for the student to take concurrently Mathematics, Chemistry and Physics (or Biology). In such instances would it not be worthwhile to explore possible relationships among the contents and aims of those basic courses to find out if a more unified approach is possible?

As I have indicated before I feel rather strongly that the core contents and the philosophy behind the basic course should not be altered when dealing with large enrolments. But questions occur: Do large enrolments contribute to a deterioration of teaching and of its aims? Does it tend to produce an impersonal environment with a consequent loss of interest on the part of the student? I am afraid the answer in both cases is largely yes. The attack of the problem demands not only resources but resourcefulness, rather than the arbitrary use of a larger number of graduate students or larger physical facilities. In fact, I have a feeling that the construction of large and monumental University Cities, believed in the 'thirties to be the answer to educational needs, has in a major way contributed to making this problem more acute during the student expansion of the 'sixties and 'seventies.

We have to explore further the possibilities afforded by some modern teaching techniques: the use of films, programmed instruction, close-circuit television. . . . These teaching aids may be very useful to illustrate basic concepts and technical manipulations, but excessive reliance on them when dealing with large groups of students may contribute to the increase of the distance between the student and the teacher. The problem is complex and it demands more than a large outlay of resources and equipment, it demands manpower.

I have referred before only briefly to the laboratory part of a basic course. It has been criticized in terms of its usefulness and it has been questioned whether the returns obtainable from it can justify its high cost, particularly when the enrolments are large. I can name an important institution where the laboratory has been dropped from the freshman course. It should be evident from what I have said before that I consider the laboratory work an integral part of any basic course in chemistry for 'this probably is where most of the students discover what chemistry really is'[5]. The laboratory work should offer a unique opportunity for developing certain habits and ways of thinking, to show that chemistry is both empirical and creative, and that the thinking is both critical and quantitative. We all still learn mainly by doing, and particularly at the age of the great majority of our students. We may quote rates of reactions again and again. But there is no substitute for understanding its meaning than to measure one in the laboratory, obtain the pertinent data, and plot them. Moreover the laboratory can be a unique pedagogical device for the introduction of some topics. I might think of calorimetry. If the student gets bored in the laboratory most probably it is because the instructor is bored with the laboratory.

The advantages of small classes are associated with the close contact they allow between student and teacher and with all the opportunities such contacts make possible. Going back to the problem created by large numbers of students let me now venture an idea. Could not the laboratory become the centre of discussion and personal interaction? To allow for this, it may require longer laboratory periods and perhaps some reorientation. It need not take the place of the large lecture but it may supplement and give meaning to it. I think it is worthwhile to explore this concept, but not leave its implementation entirely in the hands of graduate students. If this concept were implemented, to be successful it would need a proper balance between graduate students and senior faculty members. It would also need the dedication of the entire staff and a sound master–apprentice relationship among the undergraduate students, the graduate students and the senior faculty. I feel we should abandon the concept of having just a part of the staff 'specialized' in the teaching of the basic course.

Good new ideas are being presented at the Symposium, and the discussion is proving to be very fruitful. We will all come out with something for further reflections and hopefully with concepts for experimentation. But do not forget that we will have to work in a 'context' and that in the final analysis success will be determined by the irreducible relation: 'student–teacher'.

REFERENCES

[1] 'Report on the International Conference on Education in Chemistry', *J. Chem. Educ.* **48**, 6 (1971).

[2] C. Hinshelwood, in *Chemistry and Man*, E. and F. N. Spon, The Chemical Council: London (1953).

[3] C. A. Coulson: *Valence*, 2nd ed. Oxford University Press: London (1961).

[4] C. E. Ronneberg, *Chem. & Engng. News*, **45**, 50 (1 June 1970).

[5] W. T. Lippincott. *J. Chem. Educ.* **46**, 127 (1969).