

A SINGLE GENERAL CHEMISTRY COURSE FOR SCIENCE AND NONSCIENCE STUDENTS

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When chemistry curricula are discussed, the general chemistry course is usually assumed to be merely the first one of a sequence of chemistry courses leading to a major. When liberal arts curricula and the place of science in the curriculum are discussed, a common assumption appears to be that a course in the history of science, the philosophy of science, or a scientific method is appropriate. I wish to avoid the two extremes and to discuss a general chemistry course which can stand on its own merits as a course for college students regardless of their future major.

In colleges, departments other than chemistry have taught and still teach basic courses for all who are interested. A beginning course in English is taken by the science student as well as by the nonscience student. A student who wishes to learn a foreign language expects to study the language itself and not a course on the history or philosophy of the language. The student in economics or government courses expects to learn, in passing, the technical vocabulary used in these fields but he expects primarily to acquire a knowledge of economic or political problems. Similarly, a beginning student of chemistry should expect to acquire some chemical vocabulary, but he should be primarily interested in chemistry itself—the kinds of things chemists know and the present limits of chemical knowledge.

In a time of rapidly growing chemical knowledge static surveys emphasizing the memorizing of a highly selected body of material are no longer adequate. The freshman has just come from the secondary schools where memorizing of information and repeating of the information in tests and examinations were major parts of his scholastic achievement. He was not expected to inquire into or be interested in the basic premises of the subjects he was studying. But, in the freshman year in college he is introduced to a new intellectual environment. The time and place seem to be appropriate for a new approach to knowledge.

In many general chemistry courses the opportunities for the new approach have not been utilized. The students who go on to take more advanced chemistry courses are not seriously handicapped by a traditional course because in the later courses they will have the opportunity to examine the fundamental ideas in chemistry. But not all students take the later courses. May not one of the weaknesses of the past preparation of some high school teachers of chemistry be this—that the courses they studied in college were informational extensions of the high school chemistry course. Unless they completed a chemistry major they never did get enough chemistry to find out how chemists really think and act.

We must face the fact that only a rather small minority of those who study general chemistry become chemistry majors and complete the full chemistry curriculum. What can we do for those who at most study only one or two years of college chemistry? This question is of more than trivial importance in a time when science is playing an ever increasing role in our society and when educated people of all fields need to know more about it. Teachers of general chemistry in a college have a responsibility to these students. If the teachers do not rise to this responsibility, they will be passed by and the teaching of the sciences to the students at large will be done by others.

Before a mature person examines any problem in detail he looks at the problem itself in its setting. The chemist, with his interest in all material wherever it is and in whatever form it is, has the unique opportunity to take the broad view.

But, study of acids, bases, and salts, and of their water solutions, a major part of many general chemistry courses, can hardly be called broad. Even the future major who will examine the various aspects of chemistry in detail in later courses has the right to expect his general chemistry course to be general enough to give some notion as to what his future work will be.

What should be included in a modern general chemistry course? The course should really be general and not inorganic chemistry. It should start with basic ideas. At first, for pedagogical reasons, the ideas will be applied to rather simple cases but appropriate illustrations can be and should be found in all fields of chemistry. Every teacher who applies current chemical ideas to chemical problems easily brings his students to the limits of chemical knowledge where present theories are not adequate. This situation is not to be deplored; it is to be exploited. For one of the first facts a student of chemistry should learn about it is that chemistry is a growing and developing science. The nonscience student will surely not be educated if he does not understand this.

Among the basic, unifying ideas in a general chemistry course are: (1) the existence of atoms in bulk material; (2) structure of atoms (including that of nuclei and electronic fields), ions, and molecules (where they exist); (3) structure of bulk material: of elements and their compounds, and of natural materials, whether in pure gas, liquid, and solid phases, or in solutions; (4) relations between chemical composition and structure; (5) the periodic system as a correlating device for structure, size, and reactivity; (6) chemical bonding and electronegativities; (7) changes in bonding (chemical reactions), energies, and rates; and (8) chemical equilibrium. These concepts are to be applied and used to interpret the behavior of real substances.

If the student is to learn to interpret the fundamental ideas in terms of real behavior, he must have the facts available to him, for chemistry is still an experimental science as well as one with a theoretical framework. Sources of the facts will be descriptive material in the textbook or in reference material and the laboratory experience of the student.

A very general complaint of chemistry teachers is that the textbooks are too large. They are certainly too large if the student is expected to memorize all the material in them. If descriptive material is used as it should be—that is, as something to be read and referred to when necessary and as a statement of stubborn facts to which theories may be applied and tested—it becomes an aid to the student's understanding rather than an additional, unwelcome assignment. Much of the descriptive material can be in tabular form. Then relations may be more easily seen. For example, a good table of oxidation-reduction half-reactions is very helpful to the student who knows how to use it.

I have been emphasizing the understanding of basic ideas in terms of a knowledge of fundamental chemical theory. But chemistry is an experimental science. It is actual substances which react and not a set of symbols on the blackboard or on paper. Demonstrations are useful, but as far as most students are concerned they still represent reactions at a distance. There is no substitute for individual laboratory work, for it is only in the laboratory work that theory and fact really meet. Every teacher has before him a concrete illustration of the difficulty students have in understanding chemistry when he sees students who can write chemical equations easily on an examination paper having trouble writing the equation for a reaction which has occurred under their eyes in the laboratory.

Laboratory work, if properly planned, becomes a practical experience in the scientific method. Laboratory time is too valuable to be used for pencil and paper exercises. Adult chemists go to the laboratory only when they have a problem which an experiment is needed to solve. Laboratory work in a general chemistry course should also involve some element of the unknown for the student. Students generally rate quantitative experiments, such as those involving titration and the

use of the analytical balance, and qualitative analysis unknowns, as the experiments they enjoy most. Both types involve unknowns and are therefore inherently interesting. They give the student a sense of really working in a science. If he is to do the experiments well, he must do some thinking of his own. Many students even become interested in technique because good technique helps them. The student who never takes another chemistry course but who has analyzed some unknowns in the general chemistry laboratory will have developed sophistication about tests and proofs which he could not otherwise acquire.

The need for good laboratory work spread throughout the school year places some restrictions on the order in which topics are introduced in the classroom. At first glance this restriction may seem highly undesirable. The teacher may feel that the needs of the laboratory interfere with a logical order in the classroom. But an order which may seem logical to one who knows a science may not seem as logical to the student who studies the science for the first time. A logical order in a textbook is a linear order; one topic follows another in sequence. But many topics are cross-linked. For example, one cannot really understand everything on page 10 of the textbook unless he knows some of the material on pages 130 and 260. Theory, and especially new theory, is not learned overnight. One needs time in which to develop self-consistent theories and to test them with known facts.

It is, I believe, a mistake to throw too many new ideas at a student at once. I am more than willing to sacrifice some logical order if the student feels a sense of progression as he goes from idea to fact and from fact to idea. The practical requirements of a laboratory can keep one from going too fast. Indeed, many ideas are best developed on the basis of the laboratory observations of a student. "Here are the facts; how can they be interpreted?" This is a question the student faces and one we should face with him.

I have not discussed the teaching of chemistry as a historical science, as a device for teaching "scientific method," or as an introduction to the philosophy of science. Some topics, but not all, may well be treated from an historical approach. Certainly, a knowledge of how ideas develop is essential if we wish to anticipate how present ideas will develop in the future. The scientific method can only be understood by one with some experience in a science. The whole general chemistry course provides experience and should be a practical exposition of scientific method: honesty with the facts, recognition of the power of theory, cultivation of the inquiring, questioning mind, development of initiative and imagination. Then the student will know that chemistry is a growing science, that it will change in his lifetime but that not all aspects of it may be expected to change to an equal degree. He will be able to follow new developments as they are reported in the popular press and to know just what experimental facts or what new developments of theory are involved.

In the meantime, the future chemistry major has not been neglected. He will be impressed by the broad view of chemistry and by the variety of its applications, by the power of theory, by the limitations of present ideas, and by the need for future work. In the laboratory he will have developed habits of good observation on which he could draw meaningful conclusions. As introduction to the later courses in organic chemistry, analytical chemistry, and physical chemistry he will have a general setting for the more intensive and quantitative considerations. And if he still wants to be a chemist, it will be because he has a good notion of what he is getting into.