THE SCOPE OF FIRST-YEAR UNIVERSITY CHEMISTRY FOR NON-CHEMISTRY (ENGINEERING) MAJORS

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The teaching of chemistry to first-year students in an institute of higher studies (college or university) is among the more difficult problems to be encountered in the field of chemical education. In particular, this becomes a rather intricate problem when it refers to the teaching of non-chemistry majors. In the best cases, these students are subjected to a course in general chemistry in their first year of college and will probably not be required to undergo any additional tuition in chemistry throughout the rest of their undergraduate studies.

It is this special situation, in fact, which forces serious limitations even on attempts to define the problem, let alone find a solution to it. For example, we may want to ask ourselves, 'What should be the place of chemistry in the complete educational armamentarium a university has undertaken to provide for its non-chemistry students?' To try to answer this question, one would first have to reformulate the problem to a more general one, 'What should be the place of science in the university curriculum of non-science students?' Then, supposing we are wise enough to produce the proper answer to this more general question, we are faced with the very difficult, if not impossible, task of defining the exact position of chemistry in science. By its very definition, science is an indivisible entity and students as well as 'others' have to be constantly reminded that the divisions of science into physics, chemistry, biology, etc., are purely arbitrary and convenient classifications forced upon us by the limitations of human ability to master a fantastically large and ever-growing body of acquired scientific knowledge. Experience has shown that no sooner has man resorted to one such arbitrary classification, than the borderlines of the newly found divisions turn out to become so quickly blurred that additional subdivisions are necessary. This process has set us well on our way to do to science classification, for convenience, what the ancient Greek philosophers did to the bar of gold in order to arrive at the idea of the atom, the 'indivisible' particle.

The above analogy is not necessarily a far-fetched one. We might foresee a situation where any one person engaged in the pursuit of scientific endeavour will represent a 'convenient' subdivision of science, the 'atom' of science classification. And who can guarantee that the day will not come when even this ultimate 'anthropomorphic atom' of science classification will not be broken up into more fundamental 'convenient' particles, just as was done subsequently to the atom of the ancient Greek philosophers?

The preceding exercise in *reductio ad absurdum* is particularly directed to those 'specialization' educators who still argue against the introduction of science courses in the general curriculum of non-science undergraduate students.

It is quite obvious to me that the participants in this symposium do not need to be convinced of the necessity to include chemistry in the general undergraduate curriculum. On the contrary, we are here to discuss ways and means to strengthen the place of chemistry in a modern, integrated university educational system such as is required by a scientifically and technologically advanced society.

GENERAL FACTS ABOUT THE TECHNION—ISRAEL INSTITUTE OF TECHNOLOGY

The purpose of this article is to describe some of the problems encountered in teaching first-year chemistry at the Technion—Israel Institute of Technology in Haifa, Israel. It is not unlikely that similar problems exist at other universities. An exchange of views at an international symposium such as this, can make a desirable contribution towards finding answers to some of our common problems.

It may be pertinent to begin with a short general description of the Institute. Technion is the only technological university in Israel offering courses in engineering, architecture and the exact sciences, leading to B.Sc., M.Sc. and D.Sc. degrees. No degrees are offered in the humanities. Technion students in 1968 numbered 5 250 of whom 3 725 were undergraduates. Women account for eight per cent of the student body and are to be found mainly studying architecture, the exact sciences and food technology.

Admission to the Technion is based on entrance examinations in mathematics and physics. Other entrance requirements include the holding of a National High School Certificate, which is awarded to those passing examinations set by the Ministry of Education in a minimum of five subjects. Three of these subjects, Hebrew, English and Mathematics are compulsory; the two others can be chosen from a relatively large list of both science and humanities topics. Thus it is clear that since chemistry is only an elective in the national examinations, it is possible for a student to be admitted to the Technion without his having had any prior contact with chemistry. The same is not true for physics. Even though physics, like chemistry, is an elective in the national certificate examinations, the Technion entrance requirements ensure that any student admitted to study for an engineering degree will have had a certain minimum knowledge of physics, irrespective of whether the student has or has not studied the subject in secondary school.

Furthermore, the majority of students entering the Technion, do so after completion of two to three years of military service. This means that several years will have elapsed between high school graduation and the start of university studies. Whereas these first-year students, in preparing for the Technion entrance examination, will have had to refresh their secondary school knowledge in mathematics and physics, this is not so for chemistry.

The net result of this state of affairs is that 10 to 35 per cent of the students entering the Technion have had practically no tuition in chemistry in their high school studies. These students are distributed at random among all the various departments and therefore they cannot be taught freshman chemistry as a separate group.

The three science departments at the Technion, in addition to catering for their own undergraduate and graduate students, provide all the service courses in mathematics, physics and chemistry. In this way the Chemistry Department is responsible for the teaching of chemistry to about 900 first-year engineering students, as well as for providing more advanced chemistry courses for some of the Engineering Departments at the Technion.

FORMULATION OF THE PROBLEM

The Academic Senate of the Technion, in its collective wisdom, decided several years ago that the first year of studies in the four-year undergraduate course leading to a B.Sc. degree in engineering, should consist of a unified introductory course in the basic sciences, mathematics, physics and chemistry. This decision shows very clearly the Technion educators' awareness of the necessity for a science-oriented curriculum in the education of a modern engineer. Unfortunately, a not insignificant number of the students enrolled for an engineering degree appear to lack this awareness, in particular with respect to chemistry. As a consequence, one of the important tasks of the teacher lecturing chemistry to a freshman class of non-chemistry majors is to persuade his students that some understanding of the principles of chemistry could be not only pertinent to, but also very necessary for successfully practising their chosen (engineering) profession. Many years of experience have convinced me that unless the teacher succeeds in this particular task, forced upon him by prevailing circumstances, the students will merely be going through the motions of taking the prescribed course in chemistry, with little or no benefit to them and with precious time wasted by all concerned.

With this pragmatic approach, the first problem of teaching freshman chemistry to non-chemistry majors becomes primarily one of syllabus construction. Methods of presentation and teaching aids, though extremely important on their own, can and must be dealt with only after the problem of a suitable syllabus will have been solved.

RESULTS AND DISCUSSION

Several years ago we began to search for ways and means to deal with this problem within the context of the Technion situation. For example, a decision was necessary regarding the heterogeneous composition of the student body which included up to 35 per cent of students with no secondary school chemical education. It was realized that the syllabus construction alone could not solve the problem of these students and other ways would have to be found for alleviating some of the hardships that might be imposed on such students. Also, it was deemed necessary to do away with the practice of teaching largely descriptive chemistry, since the latter would have meant merely a rehash of secondary school chemistry, a situation certain to cause the majority of students to be bored, uninterested and resentful. Instead, it was decided to concentrate mainly on the principles of chemical bonding (structural chemistry) and chemical dynamics. This was the first guideline in the choice of subject matter. The second guideline was to be the application of the principles of chemistry in the consideration of materials and processes of chemical transformation which may be pertinent to various engineering fields.

(i) Lecture course

The first three years of our search and experimentation, 1966–1969, were primarily devoted to the application of the first guideline. It was felt that, initially, a basic syllabus must be prepared, common to all engineering students. Only after achieving this aim, should work be done on the selection of suitable examples, in the context of the basic syllabus, which would demonstrate the application of fundamental chemical principles to the characterization of materials and chemical processes of more or less direct interest to engineering students.

Freshman chemistry at the Technion is taught over a period of two semesters (14 weeks each) and the course comprises lectures (two hours per week), tutorials or recitations (one hour per week) and laboratory (one three-hour period per week). It was convenient, for the purpose of our experimentation, to regard freshman chemistry as consisting of two parallel but complementary chemistry courses: the lectures on the one hand, the tutorial and laboratory on the other. We shall deal with these two parts separately.

The limited total time available for lectures made it imperative to be very selective in the choice of material even within the already constraining criterion of concentrating mainly on principles of chemistry. An attempt at objectivity was made in the selection process for the construction of the basic syllabus, but it could well be that personal bias might have influenced both the choice of topics and the time allocation to each topic.

Appendix A contains a brief outline of the basic syllabus arrived at after three revisions. No claim is made that this is the ideal syllabus but it appears to be a working one which both students and teacher should be able to cope with, and further improvements can be introduced as one goes along. This programme has been tried with four groups of freshman students. In the first year, 1966–1967, the course was taught by the same teacher to two separate groups of about 130 students each. Group I comprised only students enrolled in the Department of Mechanical Engineering. Group II included students from the Departments of Aeronautical Engineering, Physics and Mathematics. A questionnaire at the beginning of the course revealed that Group I contained 31 per cent and Group II an average of 15 per cent of students without chemistry preparation in their secondary school studies.

In the second year, 1967–1968, students from the Departments of Electrical Engineering, Aeronautical Engineering, Physics and Mathematics were taken together as one group. The total number of students in this group, Group III, was 280 of whom about 32 per cent were without secondary school chemistry. For this group, the syllabus used for Groups I and II was revised, the major change consisting of reducing some of the more quantitative material and expanding the qualitative presentation of chemical bond theory. At the end of that year a second revision of the syllabus was made, mainly in expanding slightly the chapters on chemical thermodynamics and chemical kinetics.

In the third year, 1968–1969, the revised syllabus was tried with a small group of students (30), those enrolled in the Physics Department. The material was taught over one semester only, three lecture hours per week. The main purpose was to test various aspects of the basic syllabus with a group of students who might be more science-motivated than engineering students. This group, Group IV, contained about 20 per cent of students without high school chemistry preparation. The small size of the group afforded a better feedback from students, who were allowed to interrupt for questions at any point in the lecture.

A very rough comparison of the performance of the students in Groups I–IV can be made by looking at the results of the final examinations set at the end of the first semester of each year. The results are summarized in *Table 1.* These examinations, whilst not identical, were very similar and some of the questions, in slightly modified form, returned each year.

Table 1. Performance of students in chemistry examinations

Academic year	*Group*	*Students (%) with grades** *A*	*B*	*C*	*D*	*E*
1966–67	I	0·7	10·2	16·0	30·1	43·0
1966–67	II	8·9	20·2	23·1	20·9	26·9
1967–68	III	22·8	26·6	17·1	13·8	19·7
1968–69	IV	32·1	25·0	17·9	3·6	21·4

*A=90–100; B=75–89; C=65–74; D=55–64; E=less than 55 per cent.

It must be stressed that one should refrain from attempting to draw any far-fetched conclusions from the results given in *Table 1.* Our conditions of experimentation were not conducive to careful observation of the many parameters involved and the results should be considered only as preliminary observations which may help in the formulation of a more scientific investigation of the problem. From our point of view, the immediate usefulness of these results is that they have enabled us to arrive at a working basic syllabus which could serve as a vehicle for the next stages of our project, application of fundamental chemistry principles to areas of interest to engineering students, and the development of a multi-media system of teaching aids for presentation of the programme.

(ii) Tutorials and laboratory

It has already been mentioned that the tutorials and laboratory are considered to form a second chemistry course, running parallel to the first chemistry lecture course. The technical arrangements are as follows.

The first-year students in each department are divided into groups of maximum 36. Each such group meets once a week for a one-hour tutorial with a teaching instructor, usually a doctorate student in his second or third year of graduate studies. The instructor is supposed to discuss some of the theoretical background pertaining to the laboratory experiment which his group will have to carry out the following week. In addition, the instructor will go over such points from the lecture material as the students may wish to raise. Students are also required to work through problems and questions set on the material covered both in the lectures and the laboratory. There will be two or three quizzes during the semester and the averaged marks obtained in these quizzes form 20 per cent of the final semester grade in chemistry.

The same group of 36 students, under the supervision of three teaching assistants, will go in for a three-hour laboratory period each week. The students are supposed to read up in advance for the experiment assigned to them and usually the teaching assistants will quiz the students to determine their comprehension of, and theoretical preparation for, the experiment of the week. For each laboratory period, the student is graded for comprehension, experimental ability, working habits, report preparation and accuracy of results. The averaged mark at the end of the semester constitutes 30 per cent of the total chemistry grade.

A list of topics included in the laboratory programme is given in *Appendix B*.

This programme, tutorials and laboratory, has been so designed that it should, to some extent, enable students without secondary school chemical education to compensate for some of the more elementary material which is not covered in the lecture course.

Currently some of my colleagues in the Department of Chemistry are working on a revision and upgrading of the laboratory programme in an attempt to arrive at as good a correlation as possible between the lectures and the laboratory exercises.

PLANS FOR FUTURE WORK

The next stage in our programme is to select suitable examples for discussing the application of chemical principles to the characterization of materials and chemical processes of interest to the engineers. Some people may want specific examples for each engineering branch but we feel that this would be a narrow approach. However, in order to determine the special requirements of the various engineering departments, a committee has been set up comprising three representatives from the Chemistry Department and one representative from each of the Engineering Departments. This committee has already begun its work and it is hoped that some trials will already be made in the 1969–1970 academic year.

In addition, an experimental project is in progress to provide concentrated preparatory courses in chemistry for intending Technion students who have had no secondary school chemical education.

The use of various teaching aids will be tested with the idea of arriving at a multi-media system which will provide the teacher and the student with a large choice of supplementary materials, allowing for variation and adaptation according to specific needs.

Appendix A. Proposal for syllabus

FIRST YEAR CHEMISTRY FOR ENGINEERING STUDENTS

TWO SEMESTERS (Total 28 weeks)		*Total (h)*
Lectures:	2 hours per week	56
Recitations:	1 hour per week	28
Laboratory:	3 hours per week	84

1. *Introduction:* Organization of subject; scope of chemistry. Place of chemistry in the natural sciences and in the educational background of an engineer.

2. *ATOMIC STRUCTURE OF MATTER* (3 *h*)
Topics 2.1 to 2.5 should be mainly *a brief revision* of material covered in the chemistry and physics courses in high school.
2.1. Discharge of electricity through gases. Cathode rays. Thomson's experiment for determination of e/m ratio. Millikan's oil drop experiment; determination of the charge and mass of electrons. Positive particles. Isotopes. Mass spectrometer. Chemical and physical atomic weights. Avogadro's number.
2.2. The discovery of radioactivity. α-, β- and γ-rays. α-Ray scattering.
2.3. The Rutherford model of the nuclear atom.
2.4. The discovery of x-rays. The electromagnetic spectrum. Moseley's atomic number. Protons, electrons, neutrons.
2.5. Classification of elements. The Periodic Table.

3. *BOHR THEORY OF THE HYDROGEN ATOM* (3 *h*)
3.1. Black body radiation. Planck's radiation law. The photoelectric effect; photons; work function.
3.2. Line spectra. Balmer and other spectral series.
3.3. Bohr's model of the hydrogen atom. Energy of the orbiting electron. The Bohr postulates.
3.4. Failures of the Bohr theory.

4. *INTRODUCTION TO MODERN THEORY OF ATOMIC STRUCTURE* (8 *h*)
4.1. Duality of light and matter. The de Broglie particle–wave hypothesis; stationary waves.
4.2. The Heisenberg Uncertainty Principle. The Probability concept.
4.3. The wavefunction of particles. The Schrödinger equation. Atomic orbitals. Quantum numbers for the hydrogen atomic orbital.
4.4. Description of atomic orbitals. *s*-, *p*- and *d*-orbitals. Quantum number labelling of atomic orbitals.
4.5. The Pauli Exclusion Principle. Electronic configuration of atoms. The 'Aufbau' Principle. Hund's rules. Energy level diagrams.
4.6. Magnetic properties of atoms. Paramagnetism and diamagnetism.

5. *THE CHEMICAL BOND* (15 *h*)
5.1. Ionization potential and electron affinity of atoms.
5.2. Ionic and covalent bonding (classification); Lewis structures.
5.3. Molecular orbital theory of chemical bonding. The H_2 molecule; σ(bonding) and σ^*(antibonding) molecular orbitals. LCAO method. Energy level diagrams. Π(bonding) and Π^*(antibonding) molecular orbitals. Homonuclear diatomic molecules (He_2^*, Li_2, N_2, O_2, F_2). Double and triple bonds. Paramagnetism of O_2 molecule. Heteronuclear diatomic molecules (HF). Dipole moments. Bond lengths. Bond energies. Electronegativity. The hydrogen bond. Hybridization of orbitals. Localized and delocalized molecular orbitals. (CH_4, C_2H_4, C_2H_2, C_4H_6, C_6H_6). *cis*- and *trans*-isomerism in C=C structures. Other types of isomerism.
5.4. Coordination compounds: hybridization involving *d*-orbitals.
5.5. Ionic compounds. Degree of covalency in ionic bond. Energetics of ionic bond formation. Formation of an ionic solid. The Born–Haber cycle.

6. *CRYSTALLOGRAPHY* (4 *h*)
Symmetry elements. Space lattice crystal systems. Lattice planes. Miller indices. Ion size and geometry of crystals.

7. *THE METALLIC BOND* (3 *h*)
Properties of metals. Arrangement of atoms in metals. FCC, hexagonal and BCC packing. The Band Theory of metallic bonds. Insulators and semi-conductors.

8. *CHEMICAL THERMODYNAMICS* (4 *h*)
Energy states; entropy; free energy. Vapour pressure. Phase diagrams. Colligative properties.

9. *IONS IN SOLUTION* (4 *h*)
Solution formation. Conductivity of solutions. Equivalent conductance. Dissociation of strong and weak electrolytes. Electrolysis. Theory of acids and bases.

10. *CHEMICAL REACTIONS* (8 *h*)
Chemical equilibrium. Chemical kinetics. Reaction mechanisms. Equilibria in aqueous solution. Oxidation–reduction equilibria. Electrical cells. Electrode potentials.

Total estimated hours for lectures = **52**

Note:
(i) Some of the topics can be covered largely during the recitations and laboratory exercises.
(ii) The 'engineering' topics will have to be introduced where appropriate. This has been taken into account in the estimated number of hours given in the syllabus.

Appendix B. Freshman chemistry laboratory experiments

Laboratory techniques; crystallization, sublimation, fractional distillation, azeotropic distillation, solvent extraction.
Determination of chemical formulae.
Determination of atomic weights.
Determination of molecular weights: molar volumes, cryoscopic and ebullioscopic methods.
Volumetric analysis: acid–base titrations, oxidation–reduction titrations.
Spectrophotometric analysis.
Rate of chemical reactions.
Electrolysis, conductance of electrolytes.
pH determination, potentiometric titrations, solubility products.
Oxidation–reduction potentials.
Qualitative analysis of selected cations and anions.
Preparation and properties of thermoplastic and thermosetting polymers.

DISCUSSION

J. A. Campbell (*Harvey Mudd College, Claremont, Calif.*)—Much of the difficulty of teaching chemistry to engineers, physicists, humanists or other non-chemists can be minimized by selecting problems designed to show correlations with these fields. In a course including students with different interests, alternate problem sets may be effective. It may be illuminating for teachers to look hard at the problems they discuss or assign and ask whether the subjects covered could personally interest the student.

If a student after finishing a course asks, 'Why did I ever take this course?', the teacher has failed with respect to that student.

If each course, regardless of its area of specialization, dealt explicitly and extensively with the inter-relationships of its 'own' ideas to other areas, the course would generally improve by increasing student interest, by emphasizing the value of transfer of knowledge and by moving in the direction of an educated rather than a merely trained person.