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CHEMISTRY LABORATORY COURSES IN THE UNIVERSITIES OF THE U.S.S.R.

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Abstract - Many aspects of chemistry teaching in the USSR are described. Laboratory courses commonly account for 50 - 60% of university class time, and one of the major features described is the "course paper", a mini-research project undertaken in the senior years.

INTRODUCTION

In the USSR chemists receive education in institutions of higher learning of three types, namely, universities, chemico-technological institutes, and pedagogical institutes. Would-be-specialists are thus prepared for activity in three main fields, i.e., in research institutes and chemico-technological laboratories for applied research, institutes of the Academy of Sciences, and as high school and college teachers.

The requirements of graduates of universities and institutes are determined by the demands of society, thus specifying the tasks and subjects included in curricula. In view of this, the main task of university education is inculcating habits of theoretical thinking in students, whereas students of chemico-technological institutes must acquire technical thinking. At pedagogical institutes emphasis is placed on teaching methods and pedagogical and psychological expertise.

According to the "Journal of the All-Union Chemical Society named after Mendeleev" (1977, v.XXII, No. 4) there is the following distribution of chemists in the country:

Table I

Specialty	Number of Chemists % of the Total
Chemical Technology (graduates of chemico-technological institutes)	61.5
Chemistry (university graduates)	19.8
Chemistry (graduates of pedagogical institutes)	18.7

Specialists with the certificate of higher education in chemistry are the graduates of universities and pedagogical institutes, and they work in different Ministries and departments, i.e., in Ministries of a chemical character, Academy of Sciences, Ministry of Higher and Secondary Special Education, Ministry of Public Education.

Some university graduates, and the majority of graduates of pedagogical institutes, work in high schools and vocational schools, chemistry special schools and institutes.

Universities have played an important part in the development of chemical education in the USSR. They have often served as cornerstones for a large number of new, more specialised, institutions of higher learning. New scientific schools and trends originated from universities and the main cadres of the soviet sciences were educated in them. At present, the universities successfully carry out the comprehensive instruction of chemists with good theoretical background and necessary practical skills.

Would-be-specialists are instructed in -

(a) Fundamental, and

(b) Chemical disciplines.

Fundamental disciplines such as higher mathematics, general physics, analytical geometry and quantum mechanics are studied for 3.5 years. Chemical instruction during the first 3.5 years includes one-year courses in inorganic, analytical, organic and physical chemistry. The most essential feature of the instruction is that the curriculum is planned and programmed. The time allotted to narrow specialization is 1.5 years.

Training of High School Chemistry Teachers at the Universities

Departments of Chemistry at some universities have pedagogical streams. In principle there is no difference in the curricula of students, but pedagogical departments have some additional courses: psychology, pedagogy, methods of teaching chemistry, school pedagogical practice, pedagogical practice, course papers. Lecture courses in these theoretical disciplines are supplemented by seminars, where methods of teaching complex problems of chemistry are emphasized.

Some universities have departments of Chemical Education. Such courses as "Principles of Programmed Instruction", "Additional Chapters of Inorganic Chemistry", "Additional Chapters of Physical Chemistry" are given along with the basic course on methods of teaching. Many special courses are supplemented by laboratory classes.

Problems from the history of Chemistry, methods of presentation of theoretically complex subjects, different approaches to the same problems and school experiments are included in the chemistry curriculum of pedagogical departments.

Students make use of textbooks for colleges, periodicals such as "Chemistry at School", and of different books on methods of teaching (see later).

Training of Teachers at the Pedagogical Institutes

This, as at universities, goes in accordance with very definitely specified curricula, in which, along with chemical disciplines, there are also pedagogies, psychology and methods of teaching chemistry. At Pedagogical Institutes these subjects are studied more extensively than at the university. A second distinguishing feature of pedagogical education is that the studies are more professionally oriented, and pedagogical disciplines are introduced as early as in the first year; pedagogical practice is also longer. Much attention is paid to problem-solving and programmed instruction.

The important task of transition to universal secondary education by the end of the present five-year period is being carried out in our country. Universal secondary education implies improvement in the level of high school science teaching, and thus improvements in curricula and methods of presenting the subjects. Chemistry as a subject in Soviet High Schools begins with the 7th Grade and lasts four years (7th - 10th grades).

In the past decade our high schools have introduced new syllabuses in many subjects, chemistry among them. The transition period is now over. The main feature of new programmes in chemistry is the bringing of theoretical chemistry courses up-to-date. The task is solved via presentation of subjects at an earlier stage than before, and by inclusion of new problems. Some new problems aimed at more profound understanding of theory are included, namely, the structure of electron shells of the elements in the long periods, ionic, atomic and molecular crystal lattices, electronegativity of elements, thermal effects on chemical reactions, thermochemical equations, changes in the properties of hydroxides with the change in ion radii and ion charges, hydrolysis of salts, metallic bonds and the crystalline structure of metals.

The basic theory of organic chemistry is studied at the beginning of the 10th Grade. The programme of the 10th Grade also includes mechanisms of chemical reactions and isomeric concepts. The hydrogen bond is introduced.

The new programmes have had a beneficial effect on the level of teaching and consequently, on the level of attainment of students.

Improvements in teaching chemistry gave rise to new forms of instruction such as optional courses for pupils. Optional courses allow for a more profound knowledge of courses in organic and inorganic chemistry, prompt the development of interest in chemistry, and are the important means of professional orientation.

We have the following optional courses for the 9th - 10th Grades:

1. Chemistry of Metals - 9th Grade

2. Fundamentals of General Chemistry - 9th Grade

3. Fundamentals of Chemical Analysis - 9th - 10th Grades

4. Chemistry in Agriculture - 9th - 10th Grades

5. Structure and Properties of Organic Substances - 10th Grade

6. Chemistry in Industry - 10th Grade

Pupils of 7th - 8th Grades do not have optional courses.

During the transition period Chemistry teachers went through in-service refresher courses. Now that the new programmes are operative, the emphasis is upon better methods of teaching and mastery of pedagogical and child psychology.

A growing level of Chemistry teaching in high schools calls for constant attention to the qualifications of the teachers. The forms of improving teacher qualifications are various. All the institutes of our country take an active part in this work.

All these problems were discussed in detail at an International Symposium in Leningrad (17th to 25th October, 1972), devoted to the problems of teaching chemistry in high schools, on which a series of articles "Problems of Teaching Chemistry in High School" was based (Moscow "Pedagogica", 1973). Thus, much attention is paid to training of teachers along with research workers.

Fundamental skills in carrying out experimental work is of great importance in the instruction of teachers; hence the importance of this UNESCO Symposium is beyond doubt. The organization of a laboratory course is a part of the training of both teachers and research workers.

CHEMISTRY LABORATORY COURSES IN THE UNIVERSITIES

Instruction in chemistry includes lectures, seminars and laboratory courses. As in any other educational process, all these forms of instruction are interrelated providing the basis for comprehensive education. Each part of the process has its particular tasks, and contributes to the general educational goal. But, while performing its general function in the process of learning, each form of instruction performs its proper function determined by the specificity of cognitive activity (theoretical, practical, experimental), the mastery of which is achieved through the given part of the learning process, since the depth of knowledge is determined by characteristics of the learning activity of which they are a part.

Factual instruction may be effected through the individual's outside work on the material presented in lectures and textbooks, and through participation in seminars and practicals where factual knowledge serves as an orienting component necessary for the performance of a certain practical activity (solution of tasks, equations, experiments). The correlation of different elements in the process of instruction is determined by the importance and validity of each in the professional training. The proportion of lectures, seminars and laboratory courses at the university is: Lectures - 30 - 40%, Seminars - 10 - 20%, Laboratory courses - 50 - 60%. Great attention is paid to laboratory courses since they form the basis for the development of research and operational skills.

Theoretical Assumptions

Due to the increasing level of knowledge required of a student today, the role of laboratory courses is becoming more and more important since their correct organization opens up unlimited possibilities for the development of a creative scientist with good research skills. The accepted practice of chemical instruction at Moscow State University provides for laboratory courses taking up 50 - 60% of class time. The prominent role of laboratory courses is determined by the goals set for students in the acquisition of practical skills. One of the main aims of laboratory courses is the establishment of the connection between theory and practice through practical assignments.

Functions and Tasks of a Laboratory Course

1. Teaching would-be-specialists the necessary individual experimental skills.

2. Development of theoretical chemical thinking.

3. Teaching skills of scientific research work.

4. Experimental exposition of theoretical assumptions of a science under study (unity of theory and practice).

5. Development of experimental skills and knowledge of the main components of experimental work.

6. Development of skills of organisation of scientific observation.

7. Development of skills in dealing with experimental techniques, equipment and reagents.

8. Inculcation of discipline and responsibility for work.

The aims and functions of laboratory courses considered above determine the structural and systemic principles of this form of instruction.

Laboratory Courses as a Part of a Learning Process

The university curriculum includes the following fundamental disciplines;

General chemistry
Inorganic chemistry
Analytical chemistry
Organic chemistry
Physical chemistry

Every syllabus includes a laboratory course making up 50 - 60% of class time.

Let us consider the structure, content and control of a lab course.

1. The Structure of Lab Classes. A class in the lab is preceded by a seminar where the theoretical material underlying the experimental tasks of the laboratory course is discussed. Then comes the practical work which may be carried out only in the presence of a teacher, who determines the proficiency of a student after a preliminary discussion or by a programmed test. Each student makes notes in a worklog where all observations made in the experiment are entered briefly but objectively. Students enter the data, subject and aim of the work, brief description or a sketch of an apparatus, measurements, equations of the reactions and conclusions. As a rule, the entries are made in the course of work after each experiment. Students are urged to complete the description before they go on to the next experiment. To save time, part of the entries, such as date, aim, contents and drawing are made outside the class. The course of the experiment, observations and conclusions are written down in the laboratory. The worklogs are then submitted to the teacher who conducts the discussion of results for checking. Attention is paid to the adequacy of conclusions and to the aims set for the work. The marks for the work are entered into students' lab credit-test cards. Extra assessment is carried out through colloquia and credit tests. Colloquia are held once a month during the class time. The list of questions is given at the beginning of the term. Normally, they are conducted in the form of discussions but sometimes written calculation tasks are given. At the end of the term there is a credit test where both theoretical knowledge and experimental work are taken into account. If students pass the credit test the corresponding mark is entered into their credit-test cards, and they are then admitted to the examination.

2. The Content of a Laboratory Course. The development of chemistry calls for more complex laboratory courses. Tasks set should be at the proper scientific level. Thus the problem of the content of a laboratory course is very important and requires constant attention. To provide for an adequate scientific level of practical work, it should include all the important aspects of the course. For instance, the course of general chemistry should include the structure of matter and chemical bonds, kinetic and thermodynamic regularities of chemical reactions, equilibrium and properties of elements. A laboratory course which is simply a compendium of descriptions of various experimental tasks dealing with definite properties of a substance or with some particular method is not worthwhile nowadays.

In the first years a laboratory course is a well-organized part of general instruction. Students get absolutely definite instructions concerning each lab assignment, and in performing it they improve their factual knowledge. As a rule, factual instruction precedes lab work. Gradually, however, this correlation changes. A student works on the problems not yet touched upon in the lectures. Thus the situation arises when independent study and performance of a definite task become the dominating factor in the student work. In the senior years, laboratory courses become more and more independent.

3. Group and Individual Work. All laboratory work is, as a rule, individual, though in some cases group work is not precluded. In both cases, however, each student is responsible for the work. We believe that group work should be used more extensively than at present. It has a number of advantages, the chief one among them being acquisition of the ability to work as a member of a scientific group, which has become the dominant feature of scientific work in recent times.

4. A Laboratory Course as Student Research Work. Practical work may serve as a means of teaching students to carry out an experiment, and to work with literature. Laboratory courses should be organized in such a way that students are obliged to use the special chemical literature, reference books and journals. There is no need to include all necessary data and values in the description of a laboratory experiment. Students should be taught to look at various sources and reference books in order to find the necessary information. A special class should be devoted to broad introduction to the chemical literature; the principal ways of finding the necessary literature should be discussed, as well as the structure of journals and other reference material. These classes are best conducted in the library. The so-called "literature synthesis" is widely practised in the Soviet Union and is carried out by 2nd - 4th year students.

A form of independent individual work which we call a "course-paper" has proved very successful. It is carried out as a "mini-research" in inorganic, analytical, organic and physical chemistry and its importance for the development of creative independence in students cannot be over-estimated.

Usually the preparation of a course-paper includes the following steps:

(a) The selection of the literature, and discussion of each step with an instructor.

(b) The organic synthesis.

(c) The description of the process and preparation of the paper.

(d) The defence of the course paper.

(e) Report on the course-paper by the other members of the group.

The purpose of such a paper is to develop the skills necessary for research, i.e.:

- skills in the use of literature
- skills in preparing clear-cut summaries
- skills in the use of computer equipment
- skills in reporting and discussion.

5. The Course of Inorganic Chemistry. The laboratory course in inorganic chemistry takes up about 60% of class time - 160 hours in the first term and 140 in the second. Laboratory tasks, as a rule, deal with synthesis of inorganic compounds. Every student is supposed to carry out about twenty syntheses.

Methods studied by students in the first and second terms are employed in a course-paper which is an independent research study. The experimental part is preceded by a selection from the literature on the methods of synthesis, properties of substances, work with literature data. The second stage is the synthesis proper, and the third one involves the study of properties. This type of work enables the student to get his first opportunity to feel as a real research scientist. Projects make students deal with literature and think over both literature data and experimental findings. Some course papers are then published.

The following projects may serve as examples:

"Preparation and properties of oxalates of rare-earth elements"

"Synthesis of some β-diketones of cerium (IV)"

6. The Course of Analytical Chemistry. A course-paper in analytical chemistry is, as a rule, of a "literature synthesis" type. In some cases students carry out analytical research projects. All course-papers are defended and the best ones are reported at the course conference in analytical chemistry.

One of the most important and useful forms of laboratory work is the so-called "professorial task" which is an independent analytical determination of cations and anions of a complex inorganic substance or a mixture of substances.

7. The Course of Organic Chemistry. The course takes up 60% of class time; each student works out the method of synthesis of a substance, prepares it, purifies, identifies and studies some physical properties (melting point, refractive index).

A course-paper is the final step of the laboratory course and takes up about 25% of time in the second term. It is usually a three-step synthesis of a substance.

8. The Course of Physical Chemistry. The 4th year students are given a choice from a list of physical experiments or a computer task requiring the preparation of an uncomplicated programme. The work is done either in the Physical Chemistry laboratory or in another section of the Chemistry Department with physico-chemical equipment.

The defence of course papers is carried out in sessions in the presence of instructors from related fields. The themes of some papers are given below as examples:

"Some peculiarities of penetration of organic mixtures through polymer membranes".

"Automated treatment of the results of mass-spectroscopic studies".

"Statistico-thermodynamic consideration of compounds with small deviations from stoichometric composition".

"Application of dipole moment measurements in conformational analysis".

9. Treatment of Experimental Data in a Laboratory Course. The skills in treatment of data obtained are very important in the instruction of students. Students should be taught accuracy in experimental work, with obligatory mathematical treatment of data and their graphic interpretation. They must be able to use modern methods of treatment of results.

Mathematical statistics is known to be important in the treatment of results and saves effort by giving maximum information on the basis of measurements. A knowledge of statistical methods will help a student find an experimental error, estimate the accuracy of the method used, and present results with a certain degree of reliability.

Students of the first year of the Department of Chemistry at Moscow State University treat their results with the help of electronic calculators; later students are taught to use more complex computers.

Of great importance is pre-diploma practice, during which students acquire skills in using special physico-chemical methods, and have special courses in corresponding specialties. The final step in a student's scientific research is his diploma work which is reviewed and defended. A good diploma work in chemistry corresponds to the work of a doctor of the third cycle in universities of France.

10. Effectiveness of a Laboratory Course.

A. Scientific Approach to the Organisation and Procedure of a Laboratory Course. The aim of this approach is to give students a general method of dealing with scientific problems related to chemical research.

An example of such an organisation is furnished by laboratory work in general chemistry on such subjects as:

"The study of equilibrium in solutions of electrolytes by the use of a pH-meter", and

"The study of the degree of dissociation of electrolytes by the cryoscopic method".

The necessity of a better organisation of the learning process calls for new forms of structuring comprehension. The Soviet theory of learning - the theory of step-by-step formation of mental acts is based on the activity approach to the process of learning, and opens wide possibilities for a better organisation of a process. In accordance with this theory, acquisition of knowledge requires special organisation of the learning activity in the process of which knowledge, abilities and skills are formed. Together with psychologists of the Department of Pedagogical Psychology we prepared programmed aids - study cards - in order to organise the process of learning. Programmed aids were made for practical work in the general chemistry course on "Regularities of the course of chemical reactions" where we considered "Kinetic regularities of chemical processes" together with stoichiometric and energy regularities.

Making use of study cards in the material of "Chemical kinetics" we carried out an experiment to test comprehension effectiveness.

Table II

The results on the task "Rate constant of hydrogen peroxide decomposition"

Group	% of excellent marks	% of good marks	% of satisfactory marks	% unsatisfactory marks	No. of Answers	Average score
Experimental	6.7	80.0	13.3	0.0	15	3.93
Control	0.0	44.4	33.3	22.3	12	3.22

After two practical tasks ("rates of chemical reactions" and "determination of the rate constant of hydrogen peroxide decomposition") the answers to the question "why is it the rate constant and not the rate that is the main characteristic of the reaction?" were:

Table III

Group	Correct Answer	Incorrect Answer	Incomplete Answer
Experimental	100%	0.0%	0.0%
Control	44.4%	44.4%	11.2%

The results show that the experimental group demonstrated higher proficiency than the control group. Students themselves confirmed this through questionnaires and in their statements. Thus our programmed aids are the form of presentation of material which organizes the student, and gives algorythmic character to the activity.

B. Use of Technical Aids and Programmed Instruction in a Laboratory Course as a means of Increasing Effectiveness of the Learning and Teaching Processes.

Nowadays technical aids are widely used in the educational process, but usually their application is restricted to lectures and seminars and to individual work. We think that technical aids should also be used in the laboratory, since experiment is the basis of scientific and educational cognition.

What is the best way to introduce technical aids into laboratory work in accordance with scientific requirements and structural principles of the educational process? We build our work on the following principles:

(i) Principle of application of visual methods of teaching.

(ii) Principle of activation as the basic pedagogical principle.

In accordance with the first principle, we extensively use such modern visual aids as video- and sound-recording, film and slides. Wide application of videomagnetic recording will allow greater possibilities for the visual perception of experimental techniques. It will also give a student a greater independence in the preparation of an experiment. The part of a learner in the instruction process is active. To realize the second principle, students' workbenches may be equipped with consoles for computer-assisted learning.