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ARE LABORATORY COURSES NECESSARY?

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Abstract - This introductory paper reminds the Congress that Chemistry is an experimental science. A laboratory programme is associated with observations, manipulative skills, data analysis and report writing. Students' attitudes to laboratory work vary widely, and the spread of interest and enthusiasm should be taken into account when the course is designed. There should be a choice of laboratory exercises for each student, and mini-research projects should be included, particularly for the higher years. The author recommends against a final practical examination. Finally, the limitations on experimental work in developing countries, and the need for training of laboratory technicians are discussed.

It is generally accepted that chemistry is an experimental science. It has, therefore, been found necessary to include laboratory work as part of the training in chemistry. Laboratory work is supposed to clarify concepts and assist students to learn facts and theories of chemistry presented in lecture classes. Laboratory work is also expected to develop manipulative skills and train students in the techniques of handling equipment, in making careful observations, in analysing data and in writing good technical reports. In general, practical work should offer a new way of looking at things. For school children particularly, laboratory work could provide an opportunity to discover things by doing.

In spite of the laudable objectives of laboratory work and improvement in the quality of experiments being offered in laboratory courses, the reality presents a picture which is far from satisfactory. There are very few chemistry departments in the world where laboratory work goes hand in hand with the lecture material. This right away minimises the effectiveness of laboratory work in enabling students to understand concepts better (and at the right point in time). This is to some extent remedied by describing the experiments (using the blackboard, written material or audio-visual aids) just before students actually perform them. According to me, this practice has been somewhat ceremonial. Another shortcoming is the general lack of interest among senior faculty members in participating in laboratory instruction. This important task is delegated to junior staff who may or may not be enthusiastic about the work. It is likely that this trend arises from the reward system in academic institutions.

Tools of educational technology have generally been successful in improving manipulative skills, but have rarely enthused students about experimental work. Showing video-tapes of interesting experiments being conducted by chemists in real situations seemed to have received good response from students, but I am not sure how this experience can be linked to the curriculum in a laboratory course. Over-emphasis on manipulative skills *per se* is also unwarranted. Carpentry or machine shop training could equally develop manipulative skills and probably students enjoy them more. The question is whether young students can at least get the kind of satisfaction in carrying out an experiment in the laboratory as they would when they complete a carpentry project.

Although students are expected to carry out careful observations and analysis of data, in practice, most students seem to write reports by reproducing reports from seniors or classmates.

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The ability to design experiments is an extremely important attribute of experimental scientists. Very few laboratory courses that I know of seem to be able to train students in this regard. At first, I was under the impression that good instruments play an important role in making practical work purposeful. But this appears to be wrong. I have known laboratories with FT spectrometers, computer terminals and so on scattered all over the place; yet, the students complain that laboratory work is a bore. I may recall the 1974 Christmas debate organised by the chemistry undergraduate students at Oxford where they unanimously passed the resolution that laboratory work was unnecessary. Let me assure you that Oxford has one of the best chemistry teaching laboratories!

There is little doubt that students' attitudes have to be kept in mind while planning laboratory courses. Generally, it appears that good students find laboratory courses short of their expectations while the average students do their minimum to get through the courses. It has been my experience that a large body of above average students still would not know what they actually did in an experiment or why they did it, even after successfully passing the course with an 'A' grade. For some years, I have been asking the question "How does one prepare 1M HCl solution?" in oral examinations or interviews. I am sorry to report that, out of 412 graduates in chemistry, only about 25 have answered the question correctly.

In general, it appears that if students can be appraised or convinced of the purpose of the experiments they perform, laboratory courses would be more successful. The objectives of a laboratory course which the instructor has in mind may not at all be clear to students (I only hope that all of us teachers are clear in our minds as to the objectives of all the experiments in a laboratory course). Course outlines and university bulletins would just not be sufficient to describe the purpose and nature of laboratory work. It has been my experience that the actual laboratory is a real come-down compared to the flattering description flashed in course bulletins describing the course.

If we have to take students into confidence in devising laboratory courses, then, the existing system of laboratory courses in most universities in the world will have to be completely modified. This brings me to the subject of the nature and content of most laboratory courses. Most laboratory courses - whether they are in general chemistry, physical chemistry, or organic chemistry - consist of standard sets of experiments (with strict instructions) to be performed by all students taking the course. Some choice is provided in some universities. Certain laboratory courses are considered to be compulsory for all students majoring in chemistry. I feel that such compulsory experiments or courses, whether they are for chemistry majors or for generalists, have no meaning. There must be different kinds of experiments or courses meant for different kinds of students. Should there not be some difference in the nature of experiments for chemists taking chemistry courses and non-chemistry students (or generalists) taking chemistry courses? We should not forget that all students taking chemistry either at school level or at college level will not become chemists; most of them may not even become scientists. We should, therefore, consider chemistry training as part of general education.

Non-chemistry students should be able to remember their laboratory work as something exciting. If laboratory work has to be an experience to non-specialist students, then the usual qualitative or quantitative analysis will not do. Even for specialists, the kind of experiments offered in many laboratory courses cannot be exciting. I shudder to think how I ever got through gravimetric analysis and organic qualitative analysis, both of which have been considered essential for chemistry students. I have known some very well known chemical physicists who almost did not make it in organic qualitative analysis. Thank God, they somehow passed the course!

Laboratory courses at school level have to provide an opportunity to young students to 'do' chemistry, but I find that the relative importance for laboratory work in schools is coming down in many places. Also, experiments at school level do not seem to excite the imagination of the younger students. In many schools (and also in some colleges) groups of students perform an experiment and this does not provide individual experience. Experiments at schools should be something students play around with, like they do with various kits.

At college level, a large proportion of the experiments could be project-oriented at least in the higher classes. It should be possible to assign individualised projects to students depending on their interests. If such project-oriented laboratory courses (with integrated experiments) are designed for higher classes and the right choice of experiments is made available for different interests at the lower level, then, laboratory work at college level can become meaningful and purposeful. Since much of chemistry has to do with the preparation and characterization of materials, it should not be difficult to plan a large number of projects of various kinds. It is my feeling that it may be better to offer self-contained, internally consistent laboratory courses independent of lecture courses. Such courses may be more effective than lecture-cum-laboratory courses.

I mentioned earlier that the ability to design experiments as important for chemists. This can be encouraged by allowing at least some of the motivated students to freely work in laboratories planning their own projects under the general guidance of an instructor. This can be made particularly effective in areas like chemical instrumentation. I must mention here that instrumentation is one area which is ignored in most universities and yet this area is becoming increasingly important for modern research.

For those students who may take up research as their career, it would be specially desirable if laboratory courses encourage creativity, originality and resourcefulness. As far as I know, such laboratory courses are difficult to design. Serendipity is a quality that is hard to recognize and yet, this quality has been responsible for so many major scientific discoveries. Observation of nature and things around us often gives rise to brilliant ideas. Since we deal with small numbers of students at the final B.Sc.(Hons.) or M.Sc. levels, it should be possible to have special programmes for creative students (possibly using the Keller plan). Chemistry laboratory courses for higher classes could also provide valuable experience in inter-disciplinary areas like materials science. Such training would not only motivate students, but would also improve employment prospects.

I would like to touch briefly on the evaluation of laboratory work. I feel that only continuous internal assessment has meaning with regard to laboratory work. Practical examinations at the end of a course can only frighten students since they have to produce good results in a short period under the threat of examiners. I still have nightmares about my B.Sc. chemistry practical examinations. Remember that we had to get the right radicals in qualitative analysis and the right number in gravimetric analysis. Unless examinations are only meant to supplement information on students already available through internal assesment, they should be entirely abolished.

A word or two about laboratory courses in developing countries would be in order. Colleges and schools in most developing countries, including my own, are ill-equipped for laboratory courses. There are very few trained and motivated teachers. Laboratory courses in almost all schools and colleges in India at least are pitiful. If one is lucky, one may carry out a few titrations and analyze for four radicals in the undergraduate inorganic chemistry laboratory. In the physical chemistry laboratory, one may measure viscosity or surface tension of a liquid. The syllabus would, however, list a number of fairly good experiments which have generally no relation to the experiments actually conducted by students. Experimental demonstrations are few or do not exist. If a student goes further for a post-graduate degree, he/she may analyze for six radicals instead of four and will probably carry out more titrations, a situation common to most universities. Even the simplest of instruments like a pH meter or a spectrocolourimeter is not to be found in most of the undergraduate or even post-graduate laboratories. It is most desirable that resource books describing simple low-cost experiments become available to developing countries. With the purpose of popularising good experiments which can be set up at modest cost, I once wrote a book compiling a set of interesting experiments for use in undergraduate (First year B.Sc. equivalent) classes. These experiments are in fact, performed by students in my own institute. Soon I found out to my surprise that many of the universities were using the experiments from this book in their M.Sc. classes. Compounding the problems of laboratory classes in some developing countries are the practical examinations conducted by universities at the end of the year. These examinations have almost no meaning considering that there is so little in the experiments that students can perform.

One area where there is definite need for laboratory courses is in the training of chem - technicians and analysts (similar to the A.C.S. Chem - Tech programme), who can carry out instrumental analysis and spectroscopic measurements for industrial laboratories, research organizations etc. There is need for organising good programmes to train such personnel for educational, research and industrial organizations. Many developing countries are short of such personnel, particularly in chemical instrumentation. Very few technicians are available to maintain or fabricate instruments in my own country. It will be good if young teachers can be trained in chemical instrumentaion through in-service programmes.

One factor that we should not forget in planning laboratory courses is that related to the education - society interface. Some of us may take a puritanical approach and feel that as long as we teach chemistry as chemistry, that would take care of everything. A wiser approach would be to relate some of the teaching in chemistry to man's pressing problems (e.g. energy, environment and so on). We should not forget that students of today will be managers of society in another twenty or twenty-five years, when some of these problems will hit them the hardest.

Before I end this talk, I would like to point out that laboratory courses could form a good area for international co-operation and support. A survey of chemical education in developing countries recently conducted by me with the support of IUPAC clearly shows that most developing countries need help and support to develop good programmes in laboratory instruction at all levels. I hope that international bodies and agencies will keep this in mind in planning their programmes. Typical programmes that could be taken up are the preparation of resource books in low-cost experiments, regional workshops on spectroscopic methods, instrumental analysis and integrated laboratory experiments.

I am most grateful to the organizers of this Congress for giving me this opportunity to express my views on this important topic in chemical education.