Chemical sciences education at the M Sc level: What do we want and how do we go about it*

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It is frequently hoped that twenty-first century India would be a knowledge superpower in terms of manifold developments in basic sciences. The human resource necessary to propel such developments must largely be created by our universities. Therefore, in a real sense, the future of our country lies in our universities where unfortunately such realization does not appear to have taken root. There are universities where, barring sporadic syllabus revisions, the education system itself has not changed in fifty years. These are also the universities where faculty and students are not chosen on an all-India basis; instead, they are chosen almost exclusively from the particular state in which the university is situated. Note that a provincial educational institution breeds insularity and therefore such an institution cannot hope to attain the vibrancy and all-round quality of those institutions which function on an all-India basis. Paradoxically, however, some of the students from the provincial universities perform quite creditably in their subsequent professions in spite of having gone through an obsolete education system. Apart from the innate good quality of the students themselves, which cannot be destroyed even by an insensitive and unsupportive education system, a large part of the credit for such 'success' must go to the dedicated university teachers, who work under difficult and trying circumstances. Indeed, it is the teaching community which philosophizes, designs, implements, monitors and takes timely corrective actions on the entire gamut of educational reforms, e.g. at the M Sc level. In any good institution, the administrative machinery must act essentially as a support facility for teachers in order to perform various academic activities.

A question arises: If dedicated teachers and students had a dynamic, supportive and high-quality education system on their hands, what could have happened?

This commentary would make several suggestions for remodelling the M Sc education in chemical sciences at our universities[1]; limitations of time and space make it difficult to deal with undergraduate education here (see later for comments and Deb[2]). However, before embarking on the proposed education system, the following principles may be kept in mind:

Every teacher and student is a fractal point for future development[3]. They should develop an obsession to pursue excellence in their profession. The teachers should be competent, idealistic and excellent human beings, with a fierce commitment to quality teaching and research. At the M Sc level, a good teacher must be a good research worker, although the converse is not necessarily true. Teachers should take pleasure in stimulating and observing the gradual blossoming of their students' minds. They should follow the ancient Indian tradition of 'guru–shishya parampara', which involves close interactions between the teacher and the students as well as transmission of the teacher's knowledge, perception and sense of values to the students. For performing such intellectually arduous tasks on a daily basis, teachers must be in complete control of all aspects of the education system and, as indicated before, the administrative machinery should function under their instructions.

As a product of the education system, the student should have both breadth and depth over large areas of chemical sciences. Since chemistry is a central science, it overlaps all basic sciences, e.g. physical, mathematical, life and earth sciences, apart from various applied sciences and emerging technologies, such as molecular and opto-electronics, quantum computing, new drugs and their delivery systems, new catalysts, etc. It is therefore essential that we try to offer a postgraduate chemical education to students in a holistic, seamless manner, keeping the multidisciplinary and liberal-humanistic nature of the subject in mind. We should also remember that, after postgraduation, students may choose careers in teaching and/or research, development, industry, entrepreneurship as well as non-scientific occupations. Therefore, specialization at the M Sc level should be avoided. Instead, the curriculum should consist of well-structured core and elective courses, both theory and laboratory, giving a student sufficient flexibility to exercise various options in order to plan his/her individual growth. Ideally, students are the future of our society and each student, at the end of his/her education, should be like a little lamp which will illuminate a certain area. For this, students should be encouraged to develop qualities of intelligence, wisdom and compassion. We should not generate self-centred individuals who have been prejudiced against certain disciplines/activities and will therefore corrupt the education system in the long run.

Since intimate connections between structure and function constitute the central theme in chemistry, the chemical sciences curriculum should itself be carefully structured to deliver the chosen objectives (see above), as far as possible. A curriculum is also like a living organism, breathing and dynamically evolving with time. No curriculum can be perfect, but curricular reforms should not be done in a piecemeal fashion, since a change in one aspect is bound to cause changes in other aspects of the entire education system.

The present century will witness large-scale explorations of the interfaces between chemistry, biology and materials of various kinds. This should be reflected in the curriculum. Assuming a semester system of teaching, learning and assessment (see later), the following full-semester courses may be incorporated into a two-year, four-semester core: mathematics for chemists (if necessary, depending on the undergraduate programme), thermodynamics (equilibrium and non-equilibrium), quantum chemistry, organic synthesis, chemistry of main group elements, chemistry of transition metals, chemical dynamics and reaction mechanisms, chemical biology, symmetry in chemistry, computational chemistry, statistical mechanics (equilibrium and non-equilibrium), molecular spectra and molecular structure, chemistry of materials, electrochemistry in science and industry, electronics and instrumentation, etc. Note that this list is not exhaustive; additional courses may be planned.

Including theory and laboratory, the total number of classroom contact hours

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per week should not exceed 30. Sufficient time must be left to the students for self-study, work in the library and discussions.

In framing the core and elective courses, care should be taken to emphasize inter-disciplinary features instead of putting the students into watertight compartments.

Along with other courses, the student should engage in a two-semester research project under a supervisor. Advised by the supervisor, the student should exercise freedom to plan, design and execute the research project. The importance of such a research project in developing imagination, innovation, self-confidence and intellectual aggression in the student cannot be overestimated.

During the four-semester period, students should be divided into small groups, each of which may be assigned a faculty advisor who would act as the students' friend, philosopher and guide in mainly educational matters. The faculty advisor for a particular student may or may not be his/her research supervisor for the project.

Any system of science education must carefully develop both intellectual and manual skills in the student. Unfortunately, the weakest link in science education in India is the laboratory programme, where the student hardly comes across anything exciting. It is necessary for the teachers to devote time and effort in order to plan fruitful and stimulating laboratory courses. Keeping in mind that the laboratory (including a computer laboratory) is the only place where the student actually does science and, in a way, engages in a dialogue with nature, experiments can be sequentially designed to teach students various skills, techniques, concepts and phenomena, apart from giving them hands-on training with research equipments, including the computer. The students' visual pleasure can be heightened by incorporating dynamic colour changes. Students should be allowed to 'play' in the laboratory through self-planning and self-designing of experiments. Some of the experiments may be integrated – integrating techniques, concepts, phenomena, methods and disciplines – as well as open-ended experiments. For nearly thirty-five years, the present author had tried out all of these and observed that the students' responses to such innovative laboratory courses are gratifying[4]. Setting up a hobby laboratory for the students can benefit them immensely.

So far, we have talked largely about a curriculum which can hopefully reflect our aspirations for the future. It is now time to think of teaching, learning and assessment within a semester system of education[5]. First, students must inculcate regular habits of self-study, working in the library as well as engaging in discussions with teachers and among themselves. Classroom teaching should be interactive between the teacher and the students. Regular tutorial sessions for discussion, problem-solving and problem-designing should form an integral part of the teaching–learning system. Under no circumstances should students be spoon-fed, encouraged to learn by rote or treated as passive listeners. Lecture–demonstrations, which have practically disappeared from science education in India, should be brought back. Student–teacher discussions outside the classroom can be quite illuminating for both sides. The true purpose of assessing a student's performance is to employ assessment for instruction. There should be regular class tests, quizzes, home assignments (difficult to assess due to a lack of authenticity) and end-semester examinations. All tests and examinations should be internal and open (see later for research project). The teacher should finalize the marks only after showing the answer scripts to the students and discussing the answers with them. Except the question paper, the examination process should not be shrouded in secrecy. For example, open-book examinations are probably the most rigorous. There should be no end-semester examination in the laboratory courses. Instead, assessment should be done on a daily basis, based on the student's conceptual understanding, planning of experiment, handling of materials and equipments, neatness and economy of work, etc.

The student's curiosity and excitement can be fostered through regular discussions with the teachers in the laboratory. For these reasons, it is essential that the best teachers of a department also take laboratory classes. The assessment for a project may involve a seminar lecture delivered by the student on his/her research work before a panel of examiners (may include an external expert, if necessary), followed by a comprehensive viva voce. Alternatively, students may organize a mini-symposium of their research work in the form of poster presentations and be examined by all members of the department. Prizes may be awarded for the best presentations.

Finally, educational reforms must include administrative and structural reforms of the entire institution. The creaking, hide-bound bureaucratic structure of our universities prevents academic progress through numerous delays and other means. The UGC Act itself is obsolete and needs fundamental changes, through an Act of the Parliament, for effecting structural changes in our universities in order to make their administrative machinery optimized, responsive to the rapid changes in society and able to take quick decisions based on teachers' recommendations. Furthermore, in order to additionally make undergraduate education open, competitive and credible across the country, the system of affiliating colleges to a university should be discontinued. Every college should plan its own curriculum and award its own undergraduate degrees, while postgraduate education alone should be under the purview of the university. The state governments should not interfere in or try to control the state universities. Rather, the role of a state government should only be the funding of universities, apart from funding and maintaining several undergraduate colleges spread throughout the state. This openness and competition would make 'good' colleges thrive and 'bad' colleges languish into oblivion. It is worthwhile to note that all Indian educational institutions funded by the central government have acquired global reputation for excellence, with Indian teachers and students, whereas hardly any educational institution funded by a state government is in this class.

In passing, it is necessary to realize that in educational reforms there is a great deal more of talk than of action. If we do not act out of idealism, wisdom and courage, posterity may not forgive us.

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