

Chemistry Education in the 21st Century:

Challenges and Opportunities

The year 2011 is being celebrated as the *International Year of Chemistry (IYC)*. Many conferences, symposia and workshops are being organized all over the world, including India, to highlight the role, importance and achievements of chemistry. When so much is being discussed about chemistry and as the IYC is coming to an end, it would be prudent to have a critical look at the chemistry education system in our country.



CHEMISTRY is an incredibly fascinating field of study. In simplest terms, chemistry is the science of matter and the changes that take place with the matter. Chemists are people who can transform this matter into amazing things. Some chemists work on cures for cancer while others monitor the ozone protecting us from the sun. Still others develop new materials with tailor-made properties, or new textiles to be used in the latest fashions.

It is only through the wonder of the chemical work that it is sometimes possible to convert a fuel into poison, change a colour, render an inedible substance edible and replace a pungent odour with a fragrant one.

A chemist, on any given day, may be studying the mechanism of the recombination of DNA molecules, measuring the amount of insecticide in drinking water, comparing the protein content of meats, developing a new antibiotic, or analyzing a moon rock. To design a synthetic fibre, a life-saving drug, or a space capsule requires knowledge of chemistry. To understand why an autumn leaf turns red, or why a diamond is hard, or why soap gets us clean, requires, first, a basic understanding of chemistry.

Realise it or not, it is a fact that deep down we are all chemists. Every time we light a match, boil an egg or simply breathe in and out, we perform a chemical reaction. Our bodies grow, develop and function entirely as a result of the chemical processes that go on within them. Chemistry is therefore a very fundamental science that impacts all facets of our lives. Thus, studying chemistry is useful in preparing us for the real world.

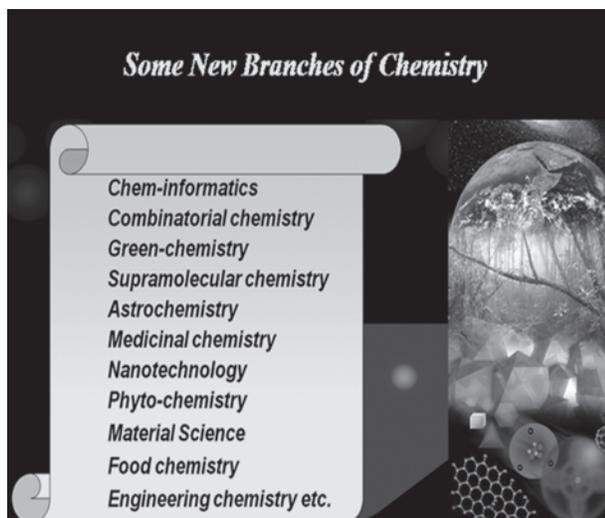
Chemistry is often referred to as the central science because it joins together physics and mathematics, biology and medicine, and the earth and environmental sciences. Knowledge of the nature of chemicals and chemical processes provides insights into a variety of physical and biological phenomena. Knowing something about chemistry is worthwhile because it provides an excellent basis for understanding the physical universe we live in. For better or for worse, everything is chemical!

Growth of Chemistry Knowledge

Chemistry is the most productive of all the sciences. It has been growing much faster than, for instance, the world population during the past 100 years. Chemists produce more research papers than all other natural and social sciences together. In 2006, for example, chemists published more than 100 times as many papers as in 1901 when Van't Hoff received the first Chemistry Nobel Prize. The most fascinating aspect of chemistry is that chemists not only describe and explain our world as it is but are also changing and extending this world through producing or making new chemical substances i.e. matter.

Year	Number of Chemical Substances*
1800	Some hundreds
Today	About 30 million
2025	80 million
2050	300 million
2100	5 billion

* Assuming the growth rate remains same.



There is also pressure on the teacher to finish the syllabus and, therefore, even though a teacher wants his students to acquire an understanding of the subject, it cannot be accomplished

capable of reading all publications of chemistry, not even all publications of a small area, being up-to-date or being universally informed and competent has,

therefore, become mere fiction for the past many decades.

The result is that there has been an exponential growth in the number of chemical substances. For example, while there were some hundreds of chemical substances in 1800, today we have more than 30 million chemical substances. This number is expected to reach 300 million by the year 2050 and 5 billion by the year 2100.

Even the number of elements in the periodic table, which were 63 in 1869, has now grown to 118. We may be reaching a saturation stage for periodic table but definitely not for the new chemical substances or compounds.

Since each substance has some basic material properties, this has led to the exponential growth of chemical knowledge.

It is, therefore, not surprising that with this unprecedented growth in chemical knowledge, there has been the emergence of many new sub-disciplines of chemistry. These include among others chem-informatics, combinatorial chemistry, supramolecular chemistry, phytochemistry, food chemistry etc.

Difficult to be Up-to-date

The growth of chemistry knowledge is increasing our lack of knowledge. In such a scenario, it has become almost impossible to stay updated in all areas of chemistry. For achieving that, one will have to read about 2000 new publications every day. If one prefers to screen only the short abstracts, one must still read 200 pages/day or about 70000 pages/year.

Since the number of publications increases exponentially, one may also have to double one's reading capacity within the next 15 years. Since nobody is

What Ails Chemistry Education?

Chemistry education in a formal sense means the teaching-learning process of chemistry and involves three important components viz. curriculum/syllabi, teaching-learning and examination. Further there is a constraint of time within which this whole process has to be completed at each level viz. +2, B.Sc. or M.Sc.

The growth of chemistry knowledge poses a serious challenge for chemistry education because this knowledge should ultimately be integrated with the education system to pass it on to the future generations. There is a need to look critically at each of the three components of chemistry education and see what can be done to achieve the goals of chemistry education in the country.

Syllabi: Chemistry syllabus or the chemistry course content for any level viz., +2, B.Sc. or M.Sc. is like a menu that we offer to the students and should be very carefully formulated keeping in mind the objectives of the course and the background of the students.

In India, science and mathematics education are compulsory up to class X. If one looks at classes IX and X science course structure, one finds that there are five units each in both of these classes besides experimental work. This secondary stage course has been built around six broad themes: Food; Materials; The World of the living; How things work; Moving things, people and ideas and Natural phenomena and resources.

However at +2 level, where chemistry is introduced as a separate discipline for the first time, suddenly chemistry curriculum becomes quite heavy and covers almost all important topics of different branches of chemistry. For example, there are 14 units in Class IX and 16 units in class XII besides experimental work. Now the questions arises: Are all these 30 topics covering all the main branches of chemistry really needed at this level? Is it not too heavy? Do we want to create interest of students in chemistry or want them to run away from chemistry? Further, there is one PGT with specialisation in one branch who teaches all these units. He/she may not be able to do justice with the topics of the remaining branches of chemistry.

For a beginner who is new to the world of chemistry, he should first of all be told about chemistry, its scope, importance and career prospects in chemistry. At class XI, one may have a foundation course of about 6-8 concept-based units covering important concepts of chemistry. In class XII one may have again about 6-8 units in which the applications of those concepts in different branches of chemistry should be discussed.

The examination at 10+2 should cover the course of both classes XI and XII. This will ensure that the concepts of class XI are seriously covered and not left out. Further, since class XII syllabus will be based on the application part of what is learnt at class XI level, both students and teachers would take interest in that. And, since the syllabus would be light, it would be possible to cover all the topics in sufficient depth and generate interest of the students in this discipline. While framing the syllabi it should also be seen that the overloading of the course content with unnecessary factual details is avoided.

In India, there is no proper coordination between school education and higher education. This is one reason why students are losing interest in science because though school science syllabi are revised regularly every five years by NCERT, the science syllabi at UG/PG levels have not been revised in many universities for more than two decades. Many of the topics that students learn at +2 level are still taught at UG levels and therefore students find all this very boring and monotonous as the course content does not challenge their minds.

Teaching- Learning: Once the syllabus has been finalized, the main responsibility to do justice with it rests with the teacher. At 10+2 level, since students are learning chemistry as a separate subject for the first time, it is the prime responsibility of the teacher to ensure that he is able to stimulate the minds of the students and invoke in them an abiding interest in the subject. This can be done if emphasis is laid on the clarity of concepts. If this is not done, the subject of chemistry becomes a phobia for students and they would always be looking for an opportunity to avoid studying it.

A teacher while teaching a particular topic should try to introduce and build it up in a very systematic and logical manner, trying to answer all the questions

Teaching profession will have to be made more attractive. Teachers like researchers should be duly recognized for their contributions in the form of awards.



of chemistry. A teacher should motivate and inspire students and should ensure that whatsoever he teaches is effectively learnt by the students. Learning does not mean rote learning—rather learning is a six-level hierarchy consisting of: knowledge, comprehension, application, analysis, synthesis and evaluation.

Our examination system should also test all these aspects of learning. If students are trained to learn along these lines from their school days, they are sure to become creative later on. In this way we may not have students with +90% marks but we will certainly have students with an in-depth understanding of the subject and creative minds. What we are facing today is the poverty of such minds as the current examination system emphasizes more on rote learning.

Students too, on their part, should work hard and utilize all their resources effectively if they want to study and learn chemistry. No teacher, no matter how gifted he or she may be, can teach you anything if you are not actively engaged in and responsible for your own learning. It will take persistence, concentration, discipline, patience and lots and lots of practice if you really want to learn chemistry.

Examination: Examination is an important component of education process as it tests the effectiveness of the teaching-learning process. Examination should not test the memory only as is generally the case in most of our examinations. Rather it should test the genuine comprehension of the subject and analytical skills of the students. Once it is done, the students will start laying emphasis on an in-depth understanding of the subject. Changing the nature of questions asked can indirectly and in a cascading manner contribute to strengthening of chemistry education in the country.

CBSE, for example, introduced Higher Order Thinking Skill (HOTS) questions a few years back and it had the desired result as all schools started laying emphasis on aspects that encourage thinking on the subject.

There must also be a continuous process of assessment rather than the present one-day assessment. Under the present system students are expected to perform very well on the examination day irrespective of everything else. Further, the present day subjective type of testing mostly leads to subjective assessment of students and hence may not be a true measure of the student's competence. Further, due to an increasing number of student enrolments and poor teacher-student ratio, individual feedback of student's performance in a test/assignment by teacher to each student is becoming increasingly difficult.

ICT in Education: Need of the Hour

In today's information age, ICT can do wonders that no one can imagine. Look at its impact in various aspects of our life. ICT has fundamentally changed the way we live now. We find a world of difference in the practices and procedures of the various fields such as medicine, travel, tourism, business, banking, engineering etc. as they operate now in comparison to how they operated two decades ago.

The impact of ICT on education, however, has been far less and slow. ICT if used judiciously can prove a big change agent for education. ICT-enabled education is not only an answer to the growing demands for enrolments in education, but is also in tune with the mindset of the present day students and helps meet the challenges of the growth of knowledge.

Hierarchy of Learning Process

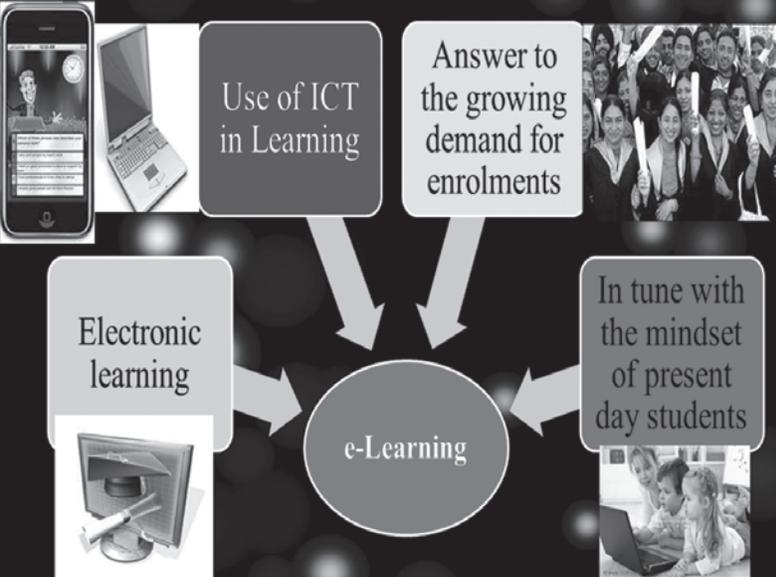
Are the Students learning effectively?

- According to a Survey* done in 142 top private Schools in 5 metros in India and 43 other countries
- Indian Students fared poorly in comparison to students of other countries in reasoning based and analytical questions.
- Indian Students did well in Questions requiring rote learning*

* Source: India Today

that can possibly arise in a student's mind. Once a student finds that all his queries have been answered and that he has achieved clarity of concepts, it will boost his confidence. All this is possible only if the teacher has done a lot of thinking on the subject and has an insight into the intricacies of the subject. Otherwise, the teacher will never be able to do justice in the class.

Teaching should not be for examination only as is presently the case. Rather it should encourage thinking on the subject and nurture innovation and creativity while retaining the excitement



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ICT, if used creatively, can make a big difference in the way teachers teach and students learn and can help students acquire 21st century skills like digital literacy, innovative thinking, creativity, sound reasoning and effective communication. Integration of ICT with education is therefore very much needed if we really want to create a holistic learning environment focusing on quality, innovation, expansion, excellence and inclusion.

To introduce ICT-enabled education one needs to have high quality multi-media enriched content in different disciplines for various courses including its multilingual conversion, capacity building of teachers and students in ICT skills and state-of-the-art infrastructure along with broadband connectivity for disseminating the content so that it reaches the doorsteps of the learners.

The launch of the *National Mission on Education through ICT* (NMEICT) in 2009 is a major initiative of the Govt. of India with an aim to leverage the potential of ICT in providing high quality personalized and interactive content, free of cost, to all the learners in higher education institutions in *anytime-anywhere* mode.

ICT in Chemistry Education

In chemistry education, ICT can provide solutions to many of the problems afflicting chemistry education and thus help enhance the quality of chemistry education in our country. For example, the regular and more frequent revision of chemistry syllabi is a very big challenge in the university system. The process is very cumbersome and time consuming as it requires going through various statutory bodies besides soliciting the opinion of various subject experts. ICT can be of great help in this regard.

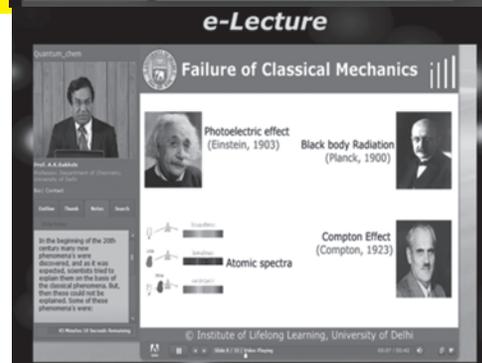
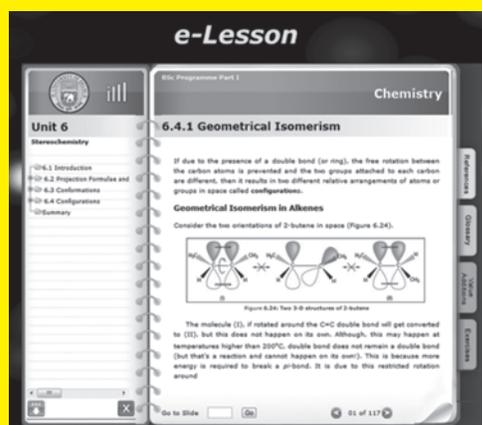
Through emails, discussion forums, video conferencing etc. experts across the country in the specialized field of chemistry can work in a collaborative manner towards regular upgradation and improvement in syllabi. They can also take inputs from industry to make the course up-to-date and relevant to industry so that the students are better employable.

ICT indeed can also play a pivotal role in enhancing the quality of chemistry teaching-learning in the country. Traditional classroom teaching, as we all know, is basically a talk-and-chalk method. However bright a teacher may be, this method of teaching does have certain limitations in the sense that many complex concepts cannot be well explained just on the board and one does feel that had there been some technological aids, teaching and learning could have been more effective.

Besides, there is also pressure on the teacher to finish the syllabus on time and, therefore, even though a teacher wants his students to acquire an in-depth understanding of the subject, it cannot be accomplished for want of time. Added to this are other factors like heterogeneous group of learners and the poor teacher-student ratio. The result is that the education system in the present form cannot meet the demands of growing needs for quality education.

ICT can help in overcoming these limitations by supplementing the present conventional mode of teaching-learning with e-learning. To introduce e-learning in chemistry one needs to develop high quality multi-media enriched e-content in chemistry.

This content could be in the form of e-Lessons, e-Quizzes, e-Labs and e-Lectures. While e-Lessons provide quality content with multi-media enriched value



additions such as *common misconceptions, points to ponder, interesting facts, did you know?* etc., e-Quizzes in the form of MCQs of different difficulty levels provide the student a mechanism for self-learning and assessment through a complete, logical reasoning of the correct as well as incorrect answers.

The concept of e-Lectures or live lectures enables the best faculty members to reach out to students across the country, thereby not only connecting classrooms but also giving students quality learning material. Multi-media enrichment of e-learning material helps communicate difficult concepts in simpler ways and thus, offers unique advantages in the field of chemistry education. For instance, text alone does not allow learners to visualise the 3D organic molecules to understand their reactions and mechanisms.

Softwares for drawing and visualising 3D chemistry structures, plotting graphs, predicting NMR/UV/IR, interactive periodic table, animations and simulations can enable teachers to provide a way by which learners can understand chemistry in an exciting manner.

In chemistry education in our country, unfortunately, the focus on experimental work is not as much as it should be. Here also ICT can play a very important role.