
Chemical Education:

Where We've been; Where We are; Where We're Going

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As the title indicates, this paper will try to look at where chemical education has been, where we are now, and where we are going. The discussion of *where we have been* will focus on our earliest traditions and the lessons and legacies our predecessors have bequeathed to us. *Where we are now* will be examined from the perspective of what historians 100 years from now may say about chemical education in the 1980's. The view of *where we are going* will examine the challenges we face as chemical education becomes an independent branch of chemistry.

Where We've Been

Our Earliest Traditions

Our earliest traditions as chemical educators can be traced back to the first Western chemistry texts by such authors as Andreas Libavius and Jean Beguin who established the philosophy, practice, and tradition of chemistry that extended until at least the time of Lavoisier.

Libavius (1540-1616) was the author of the first chemistry textbook in the modern sense. His "*Alchymia*," which appeared in 1595, treated a variety of subjects ranging from the preparation of compounds such as *spiritus fumans Libavii* (SnCl_2), to discussions of making sugar candy, coloring glass, and extracting alcohol from beer and other fermented liquors. It even included designs for a chemical institute complete with a main laboratory, analytical laboratory, chemical store room, preparations room, crystallizing room, and a facility that is all too often neglected in the construction of modern laboratories: a wine cellar. Jean Beguin was the author of "*Tyrocinium Chymicum*," or "The Chemical Beginner," first published in 1610, which was the most popular chemical textbook during the 17th century, appearing in nearly 50 editions.

Between them, Libavius and Beguin provided us with an indication of the goals of chemistry textbooks which might still be kept in mind by present authors.

- 1) The book must contain a faithful and thorough presentation of the accumulated literature on the chemically related arts while eliminating all references to the mystical or visionary.
- 2) It must be rigorously organized. The organization pattern used by Libavius was: definition of the art, description of its instruments, discussion of operations, and then prescriptions for preparing substances.
- 3) It must not present the author's own art or his personal perception of the subject; it should only present what has been confirmed by legitimate practitioners of chemistry.
- 4) It must develop and use a method of reasoning and a pattern of logic so that future workers can sort out the reliable from the unreliable.
- 5) Whenever possible, it should address the question: What is the meaning of all this?
- 6) Whenever possible, it should demonstrate that chemistry is a legitimate, independent discipline—one that can be sustained by its own integrity and one that can produce both practical knowledge and philosophical truth.

These traditions were extended by William Cullen and his student, Joseph Black, in their lectures at Glasgow and Ed-

inburgh Universities, which were published in 1803 shortly after Black's death. Cullen and Black, aided by a Scotch penchant for utility, identified and unified principles which were unique to chemistry, thereby preventing chemistry from being swallowed up by Newtonian natural philosophy. Their explanations were later expanded, codified, and systematized by Lavoisier, and therefore served as the basis for much of what we still do today.

Legacies and Lessons

The work of these early chemical educators left us with four legacies we still carry with us.

- 1) A knowledge of how to use language to teach, to organize information, to promote clear thinking, and to stimulate intellectual investigation.
- 2) The obligation to teach not our own perception of chemistry, but what has been confirmed by practitioners of chemistry.
- 3) The incentives and skills to do what is necessary to reach and interest our audience, regardless of its composition.
- 4) The desire to know the meaning of it all, and to affirm truth and utility as the twin goals of chemistry.

They have also provided us with six lessons.

- 1) Teachers as well as researchers are responsible for changing chemistry.
- 2) Chemistry instruction does not take place in a social and cultural vacuum.
- 3) Those we teach must claim priority over what we teach.
- 4) Chemistry is chemicals and chemical processes made understandable by theory, and not the reverse.
- 5) Chemistry as a way of thinking and a way of doing must be communicated to students.
- 6) Every few years the whole thing changes.

A Pragmatic Look Back

In retrospect, the traditions, legacies, and lessons bequeathed to us have produced a system in which the record of our science-career students is outstanding. Unfortunately, our record in improving the scientific literacy of the general population is poor. We have shown that we can accommodate to change, but we are neither as bold nor as creative as our best researchers. We have awakened to the needs of our students, but we have not learned how to deal successfully with these needs. We have recognized the need for a humanized science, but we have yet to contribute to creating it.

Where We are Now

What Historians 100 Years from Now May Say of Us

A hundred years from now, historians may say that by the 1980's, chemical education had emerged as an independent, self-sustaining subdiscipline of chemistry. It had established its own structure and canons of conduct. It had begun to create its own procedures for research and developing theories. Furthermore, individuals had begun to specialize in computers, learning theory, managing large programs, etc.

These historians may also note that our greatest flaw was

a failure to reduce the endless mass of chemical information into a comprehensible, learnable, professionally acceptable package that can be used by beginners. They might say that

- we had more opportunities, more things going, saw more changes, and were subjected to more new ideas than any previous group of chemistry teachers.
- we experimented with new curricula, and new approaches to teaching.
- we developed a sustained interest in how and why students learn.
- we were ingenious in using computers and audio-visual technology.
- we made great progress in rapidly getting new knowledge into the classroom, and improving the competencies of teachers.

They might also suggest that we were aware that our teaching had made a difference; that it had paved the way to the most productive and creative period in the history of chemical science; and that it had led to far-reaching applications of chemical principles in biology, medicine, nutrition, geology, astronomy, engineering sciences, and in nearly every area of technology.

They might note that we were confronted with a mass of chemical information so large it was becoming incomprehensible; and that we encountered for the first time the problems of chemical hazards in the environment and the limits of natural resources. Finally, they might note that we suffered from public distrust of chemistry and technology which led us to recognize that the likely consequences of continuing and deepening public distrust might be avoided if the public could understand the chemical and other scientific realities involved in key issues. Unfortunately, these historians also might note that we were reluctant to undertake the major reform of chemistry instruction needed to make chemistry more comprehensible and more useful.

A Psychological Perspective

The chemical education community today is reeling with unprecedented success. It is also staggered by the complexity of its mission and opportunities. It is taking chemistry for granted and has allowed its sensitivities to so outreach its ability to control things that it is in danger of exploding into a shower of ambiguities. We need to establish order, do more planning, select realistic priorities, and return to our first love—learning, doing, and teaching chemistry.

The Climate of the Times

Science and those who understand it are moving us at a pace too fast and in directions too foreign for the well-being of many of our people and for the long-term viability of our social structure. Too many young people are unprepared to function productively in the society in which they must live. The public is wise enough to know that chemicals, like fire, are a mixed blessing—but a blessing nonetheless. The people expect us to care and to show that we care.

Where We are Going

Research in Chemical Education

The symposium on research in chemical education held during the St. Louis ACS meeting suggests that much is going on in this area. The papers by Johnstone and Herron in this State-of-the-Art Symposium are further evidence of this fact. At long last, there are mechanisms in place to do good research in chemical education. There is the ICE project at Wisconsin

and graduate programs at Purdue and Maryland, and work presently underway at Nebraska, UCLA, and Texas, to name just a few institutions.

Some areas in which this research is headed include research on the basic goals of education, criteria for content selection, teaching and learning methods and techniques, criteria for assessments, and the development of models and theories.

Fostering Excellence in Precollege Science Education

We must do something substantive with K-9 science education. Research shows that by the 3rd grade, about 50% of the students want no more science; by the 8th grade, more than 80% want no more science. Problems associated with teacher preparation, with working conditions for teachers, and with curricula offer great challenges, but they are challenges that must be dealt with.

In secondary education, we must recognize that we cannot educate top scientists and informed citizens with a common curriculum. We must therefore revise traditional secondary school chemistry courses and create alternatives to these courses that meet the needs of students who are being poorly served by the existing curriculum. We also must help our secondary school teachers expand their influence and effectiveness, thereby creating a new concept of professionalism.

Making a Quantum Leap Forward in University Chemistry Instruction

University chemistry instruction has not kept pace with either advancing chemical science or advancing educational technology. Today's chemistry curriculum is in the parts per thousand stage, while chemical science is working in parts per billion. Today's curriculum is geared to thinking in terms of diagonalizing matrices by hand while our machines do a Fourier analysis in 40 μ s.

We must go beyond textbooks and lecturing in our classes. Computer techniques can be used to substantially improve on certain aspects of what textbooks do, and they can also be used to replace many of the less creative components of lecturing. By using computers in this way, both the live professor and the textbook can become more effective at what they do best.

There are many ways in which computers will help us go beyond textbooks and lecturing. A computer in front of the classroom can be as handy to use as a piece of chalk. In-class, instructor-managed computer learning can provide us with a new, more effective way of presenting information. The computer can provide us with a totally new model for teaching instrumentation. It can show how quantum mechanics is applied, and therefore make quantum mechanics "real." It can simulate molecular motion in a quantitative fashion. It can provide us with better ways to teach synthesis and structure-behavior relationships.

Scientific Literacy and Humanized Science

We will have failed a solemn trust if we do not make genuine progress in scientific literacy and humanized science before the end of the century.

Conclusion

As multi-dimensional and confusing as it is, we have before us the greatest opportunities chemical education has ever seen. What we need now are 100 geniuses to dedicate the next 20 years of their lives, each one to a different aspect of our mission.