Chapter 2

Questions to Chemical Educators from the Chemistry Community

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This chapter poses twenty questions whose answers are of vital importance in teaching chemistry to beginning students at the college or university level. These questions are addressed primarily to those who carry out research in chemical education, but the argument is made that the answers provided by this community of scholars will have little impact unless chemists and chemical education researchers can communicate clearly to one another and gain not only each other's respect but also the attention and respect of the wider chemistry community.

Chemical education research is similar to research in the chemical sciences. The investigator begins with a question, defines what needs to be better understood, designs experiments to collect data, analyzes the collected data using the most sophisticated tools available, and fully discloses the work in the form of refereed publications and conference proceedings. Reflection on the validity of the hypothesis compared with the observed findings creates new

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questions, requires modification of the original propositions, and so on. Yet, most chemists feel much more comfortable with research on chemical problems than research on chemical education problems. Why is that so?

I suspect it is because of the inherent complexity of chemical education problems. The evidence that chemists find compelling is usually quantitative rather than qualitative, and we tend to distrust experiments that cannot be exactly reproduced. It is easy to argue that presenting the same material in the same fashion in different classes will yield different results just because different students will be present, and this fact leads some chemists to scorn all efforts to investigate which teaching approaches are most effective. Chemists are drawn to the study of pure substances under conditions where the response of the chemical system results in a linear change with the experimenter's variations of the initial conditions. But research on teaching and learning is not like that.

Actually, the chemical world is not like that either. Chemists are increasingly aware that by avoiding complexity and heterogeneity they can miss important discoveries, such as the details of how living cells work. Thus, while chemists might be skeptical of chemical education research in the same way that they are skeptical about the social sciences, this research area is not only a valid one but one that holds huge potential for practical gains in preparing the next generation of chemists. Nothing is more fundamental to the future of the profession than attracting talented young women and men to the pursuit of the chemical sciences and providing them with an education adapted for solving problems at the cutting edge of our field.

Chemists and chemical education researchers have this goal in common, but it fails to unite their efforts. The findings of the two groups often are described in separate jargons and almost always published in separate journals. In a speech to the Northeast Section of the American Chemical Society, Dr. Robert L. Lichter, then Executive Director for the Camille and Henry Dreyfus Foundation, commented on this separation (*1*):

> There's a tendency to divide the chemical universe into two groups: the educators and the doers. Conferences and other gatherings on the topic [of education] tend to be directed to those called the former. I suggest that this is a highly limited perspective and does the profession and the practice, and certainly the students, a disservice.

I myself would divide the chemical universe into chemical researchers, chemical educators, and chemical education researchers. Only a few people belong to all three groups but many if not most people belong to two, while it cannot be denied that some people identify themselves as belonging to only one.

George Bernard Shaw wrote in "Maxims for Revolutionists," an appendix to his play *Man and Superman*, the infamous lines (*2*):

> He who can, does.
> He who cannot, teaches.

The corollary has been proposed (*3*):

> He who cannot teach, teaches teachers.

This painful put-down of teaching and research into understanding how students learn expresses a common attitude among chemistry faculty members in institutions of higher learning -- institutions where the integration of teaching and research remains more a mantra mumbled by administrators than a practice embraced by professors. The incentive system at research universities has historically rewarded scientists richly for making discoveries and publishing academic papers but poorly for nurturing students, some of whom will become the next leaders. Moreover, it is easy to construct metrics for measuring research productivity but much harder to do the same for teaching and mentoring. And what metrics are we to use for chemical education researchers? Clearly, this activity has many variables to handle, large questions to examine, and different tools to use in its experimental design, but it is commonly dismissed as a second class activity by many chemists at research universities.

Most faculty members originally became professors because they believe that teaching is a noble endeavor; teachers influence lives and shape futures. For many years chemists have exchanged ideas about effective teaching at meetings and in peer-refereed journals. Unfortunately, this activity is not regarded as a mainstream responsibility for all chemists who teach. I strongly endorse the sentiments expressed so eloquently by Coppola and Jacobs (4): "In general, the scholarship of teaching and learning shows great promise for enriching and supporting chemistry education because it seeks to make systematic, scholarly thinking about teaching and learning a part of every faculty member's life, rather than just those who have claimed its specialization."

What do we know about what makes a student choose chemistry as a career path? A consensus has emerged that undergraduates need early, engaging hands-on experiences in the laboratory and much more mentoring than most of them presently receive to maintain their interest and inspire them to take up careers in the sciences, if not chemistry. A means must be found to enliven a dry and dispiriting style of science instruction that leads as many as half of the country's aspiring scientists to quit the field before they leave college. Many, including me, feel that the nation's future is at risk without investing in better science and math education for the next generation (*5*). The time has come to ask chemical education researchers for their help in carrying out the heavy responsibilities of being a university chemistry professor. I want them to address questions whose answers will help chemistry professors apply sound and proven principles to their teaching.

What follows is a list of twenty questions that I would like to see addressed by chemical education researchers – but to which all chemical educators are invited to contribute. The list captures for me some (but not all) of the perplexing problems that chemistry instructors confront. These questions are put forward by someone who has taught beginning chemistry students at Stanford for nearly 30 years but has never received any formal training in chemical education and in no way considers himself a chemical education researcher:

1. What makes introductory chemistry courses so hard for students?

2. Why do some students steadily improve while others steadily decline in beginning chemistry courses?

3. How do we make chemistry courses about learning rather than about getting good grades?

4. What is the importance of lecture demonstrations?

5. What is the importance of the beginning laboratory experience?

6. How should we teach beginning chemistry students with widely different backgrounds?

7. How significant is a teacher's choice of a definite curricula?

8. How significant is teaching style?

9. What role should instructional technology play in teaching and learning?

10. How can beginning faculty members improve teaching skills?

11. What factors make undergraduates major in chemistry?

12. What is the right balance between teaching and research demands?

13. What aspects of teaching the chemical sciences are unique to chemistry?

14. What should we put in and what should we take out of the chemistry curriculum?

15. What are the advantages and disadvantages of team teaching to student learning?

16. What chemistry should we teach to non-science majors?

17. How important are group learning activities to student learning?

18. How important is it to develop the communication skills of students?

19. What should students know about using the chemical literature to become practicing chemists?

20. What are the successful strategies for solving chemical problems?

No claim is made that these questions are new ones. They have been and are being addressed by chemical education researchers, but the results are largely unknown to the greater chemistry community, because they are usually published in chemical education journals for an audience of chemical education researchers. This failure to communicate results to chemistry instructors adversely affects their ability to teach.

Let us examine one example of this communications failure. The *Journal of the American Chemical Society* (JACS) was founded in 1879 and is regarded to be the flagship journal of the American Chemical Society. JACS claims to be devoted to the publication of research papers in all fields of chemistry and publishes approximately 17,000 pages of new chemistry a year. You will find between its covers articles, communications to the Editor, book reviews, and computer software reviews. But, you will seldom if ever find anything in JACS about research in chemical education. The consequences are the institutionalization of a divide between chemists and chemical education researchers – a divide that prevents either group from seriously influencing the actions of the other. A litany of other such examples of peer-reviewed chemistry research journals being blind to chemical education research can be recited. Of course, the argument goes both ways. Some chemical education research articles are so full of jargon and so strongly focused on impressing other chemical education researchers that they are nearly impenetrable to chemists. The blame game is not interesting; doing something to promote communication between these two groups is truly valuable. I strongly advocate that these two communities must speak more to one another, or suffer the consequences of both being impoverished by this lack of information and opinion exchange.

I hasten to admit I am not sure of the answers to the twenty questions posed above, but I do have some thoughts. Many students begin my introductory chemistry course with a sense of dread, believing that the chemistry department is a gatekeeper that stands in the way of their achieving their aspirations, or often more correctly their parents' aspirations, that they become medical doctors. This sad situation is common in the United States, and it challenges many chemistry instructors. However, the same class contains students who will discover that the study of chemistry fires their imaginations and opens new possibilities that they never considered before. With all of this in mind, I have thought a great deal about the first of the twenty questions that I posed: why is an introductory chemistry course so hard for students? Most students experience a learning discontinuity between high school and college chemistry. The former frequently rewards memorization, recitation, and using algorithms to solve word problems, whereas the latter often demands reasoning from understood concepts. Many students work very hard in the same mode that was successful in high school chemistry only to discover that this approach is like hitting your head against the wall. All of us who teach introductory chemistry hope to find a way for students to come to this realization prior to receiving poor marks on exams. How do you do this?

My own approach has been to give many small exams called homework. Homework counts for very little of the final grade in the course, but these students have gotten to Stanford by always completing assignments. The homework assignments are important in communicating to them the type of skills that they must acquire to succeed in this course. I point out that no one learns how to play the piano by reading a book on how to play the piano. In the same way, working problems is what they need to insure that they have secured mastery of the course.

It is my experience that students who drop out of beginning chemistry do so because they fall behind, panic, and reach a state of mind where rational discourse and even intense intervention are futile. To prevent this state of collapse, I assign homework in each lecture that is due at the next lecture. I encourage students to work the problems on their own at first, then discuss them with classmates. Because I grade the course on an absolute basis, the students are not competing against each other for grades, and I encourage them to work together by assigning them to study groups. These groups are based on geographical proximity, taking into account what dorms the class members reside in. I find that self-selected study groups tend to leave out some class members. This conclusion is not original but builds on results obtained by many others.

More important than the opinions I presently hold on how the twenty questions might be answered is the fact that these opinions are subject to change. As I listen to others and reflect on the other chapters in this book, and as I try various approaches on my own students and observe the results, I sharpen and refine my own thinking on these questions. It is the quest that matters. An old Chinese proverb states (*6*): "Teachers open the door. You enter by yourself." But different people have different doors. What may be an open door for one student may be a wall for another. It is saddening to realize that no one correct set of answers probably exists to these questions. Conversely, multiple teaching approaches simultaneously available to the students of a class may open the most doors. Here is where chemical education research can show which of many different approaches works best for which student.

Certainly, it is important to try different teaching approaches. Experimentation – which always means risking failure – is at the root of almost every success. That adventurous spirit is required to succeed at developing new teaching methods, improving curricular content, and systematically testing which is best and why in which situation and with which student. Assuredly, teachers must honor the best of education's established practices, but they must not shy away from investigating new methods to reach students. And chemical education research can help us discover which methods work well. Instructional methodology must be perpetually evaluated and improved upon – or discarded as ineffective. Just as in research, what is needed in teaching is a spirit of playfulness combined with critical evaluation and assessment of the outcomes.

Let me return to George Bernard Shaw's quote that began this short chapter. I endorse Lee Schulman's sentiments when he wrote (*7*):

> "We reject Mr. Shaw and his calumny. With Aristotle we declare that the ultimate test of understanding rests on the ability to transform one's knowledge into teaching. *Those who can, do. Those who understand, teach.*"

to which I should add, and those who seek the connection between the two do chemical education research. To paraphrase how Schulman concluded his essay, I would write:

> Those who can, do.
> Those who cannot, do not.
> Those who can do, and who can teach and reflect on what makes teaching effective, do it all!

We still have so much to learn about teaching chemistry and the first step is asking good questions. But posing questions from the chemistry community to the chemical education research community is not enough. Unless both communities deepen their respect for each other and exchange more information and ideas between them, the answers provided by chemical education researchers are likely to fall on deaf ears.

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