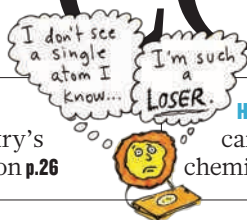


COMMENT

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Design innovations such as Princeton University's Frick Chemistry Lab need to be matched by a radical rethink of priorities and teaching methods.

Let's get practical

Chemistry needs an overhaul if it is to solve big global problems and advance fundamental understanding, say **George M. Whitesides** and **John Deutch**.

Chemistry is at the end of a century of expansion. In 1900, the chemical industry was in its infancy. The modern research university was still 50 years away, and the basic concepts of the field — the chemical bond, the laws of thermodynamics, theories of kinetics — were still being developed. In 2011, the industry is mature and fully embedded in society, and chemists have a good, semi-empirical grasp of many of the characteristics of molecules and reactions. Academic chemistry is established, and with its maturity has come an increasingly incurious and risk-averse attitude. So, what's next? 'Business as usual' is not an option. To solve new problems, chemistry must be braver in its

research choices and in how it organizes them. As it grew, academic chemistry splintered into many specialized subdisciplines such as organic synthesis, coordination chemistry and laser spectroscopy. This structure worked adequately for the relatively simple problems of the past century, but it will not work for the more complex problems of the next, such as global stewardship of natural resources. The field requires, and is undergoing, a fundamental change.



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Chemistry rests on three unequal legs: industry, academia and government. Of the three, only universities have the freedom and flexibility to take chemical science in new directions. Industry develops engineered, manufactured products; these should in principle solve societal problems, but must in practice be profitable. Under the short-term constraints of capitalism, industry has largely retreated from long-term research, and mostly focuses on incremental innovation. Government influences research through policy — how funding is allocated between fields, or tax credits for innovation, for instance — but influencing the direction of science is usually incidental to other political agendas. ▶

► Universities have fewer constraints.

Current societal problems are too complex for a collection of conservative disciplines. They require a chemistry that is motivated to solve problems about which people care (and for which they will pay). ‘Solving practical problems’ is often claimed to vulgarize science. It does not: many of chemistry’s fundamental discoveries were made in the course of developing practical technologies — catalysis and polymer science, for instance, had their origins in industry. And such problems are often more challenging than the questions fashionable among academic chemists, driven as they are not by unfettered curiosity but by a conservative peer-review system — the spigot that regulates the flow of government funds.

Chemists must remember where the money comes from. Citizens reluctantly allow governments to collect taxes and to spend a minuscule fraction of that money on science, in the faith that by doing so, research will ultimately generate a better world: better health, less conflict, interesting jobs for their children. If that faith falters, the investment will slow or stop.

When funding is flat, the temptation in academia is to retreat to the departmental bunkers. But if chemistry as a discipline is poorly equipped for today’s problems, it will wither before the challenges of the future. Reinvention is essential for the continuing relevance and survival of the discipline.

GLOBAL CHALLENGES

Chemistry is the science that connects the relative simplicity of atoms and molecules to the complexity and function of macroscopic matter and of life. Some of the most interesting problems in science, and many of the most important facing society, need chemistry for their solution. Examples include: understanding life as networks of chemical reactions (reactions occurring in water, that most peculiar of solvents); interpreting the molecular basis of disease; global stewardship; the production, storage and conservation of energy and water; and the management of carbon dioxide.

Chemistry — fundamental and applied — has been slow to exploit these research opportunities, and even the best academic chemists have a Prussian-like loyalty to the status quo. Universities that consider themselves the most innovative and radical in their thinking, and that should be in the forefront, are in the rear, defending already familiar and well-established fields.

Cracks in the 100-year-old structure of chemistry began to emerge in the 1990s. First, it became clear that chemistry’s best intellectual opportunities lay outside its historical boundaries. The new frontiers were the life sciences and materials science. Now others — energy, the environmental sciences, complexity and affordable health care —

offer additional and perhaps even more compelling opportunities.

Second, ‘function’ replaced ‘structure’ as the objective. Molecular structure is now easy to define and manipulate in chemistry; function is hard to achieve, especially by design, and usually emerges from empiricism and serendipity. Society does not care if a molecule has a particular structure; it cares if a pill lowers blood pressure, or a panel generates electricity when exposed to sunlight.

Third, academic chemistry is overpopulated. The proliferation of PhD programmes resulted in a demand for research funds that exceeded the (much-expanded) supply, and the imbalance of supply and demand contributed to a peer-review system that protects established fields at the expense of new ideas. These PhD programmes produced too few new ideas and too many average scientists, and neither provided novel solutions to problems (or jobs), nor caught the attention of the public.

Finally, Balkanization of the field has led to specialization in young scientists. If

“Society does not care about molecular structure; it cares if a pill lowers blood pressure.”

understanding the molecular basis of life requires integrating a high level of expertise in organic reactivity, kinetics, dissipative systems, biochemistry and cell biology, who is to do it?

Probably no single person — and certainly not a young scientist trained narrowly in a technical apprenticeship — has the range of skills demanded.

So far, the field has responded timidly to these pressures. One tentative step is reluctant participation in interdisciplinary programmes and ‘centres’. This is a compromise: it recognizes the problem, but does not really solve it. True, centres avoid some of the pitfalls of conventional academic departments, and expose their members to much wider thinking, but reactionary departments remain firmly in control of hiring and promotion. Another is to experiment with new specializations. Departments focused on nanotechnology or biological and medicinal chemistry have sometimes prospered. But exchanging an old specialization for a new one is hardly a sustainable strategy for restructuring a field.

REAL-WORLD SOLUTIONS

Here is what chemists should do instead:

Rewrite the social contract. Chemistry must reorganize to try to solve problems that are important and recognizable to the society that is paying for the research, especially those to do with water, food, health, energy and the environment. To make fundamental discoveries, an approach that starts with practical problems, and uses them to reveal

unsolved fundamental problems, will work at least as well as (and arguably better than) one that starts with the familiar questions of familiar disciplines.

Do away with the old disciplinary structures. Disciplines mature, and must be subsumed into others. Chemistry should cluster its teaching and research around the exciting and uncertain future rather than the ossified historical past. A first step is to merge chemistry and chemical-engineering departments. A second is to form broad new entities that address the most challenging problems that require the skills of chemists. Plausible topics could include functional materials, catalysis, complex dynamic networks, energy, the environment and sustainability, health and out-of-equilibrium systems.

Focus on chemistry’s strengths. Chemistry has unique capabilities in many areas: complex kinetics, biological and environmental networks, synthesis of new molecules and forms of matter, examination of the properties of molecules, relating the properties of molecules to the properties of materials, and many others. A focus on these intellectual strengths avoids being second-best in someone else’s game.

Teach students, rather than use them. Many subdisciplines of chemistry still use an apprenticeship model in which a professor conceives the problem and strategy, and graduate students execute the bench work. It is hard to imagine a worse way to prepare tomorrow’s chemists to work at the integration of many disciplines. Instead, professors should teach students the tools of curiosity. An independent, engaged student, exploring as a colleague in a promising area, will do better work than a simple apprentice.

Chemistry must also change its coursework, to include the hard parts (the role of solvent in chemistry, the importance of thermodynamics in biochemistry, the centrality of mathematics to the study of networks, the subtlety of catalysis and systems of coupled catalysts). It must also include ‘non-science’ subjects — especially economics and corporate finance and manufacturing — useful in generating practical technologies.

A focus on the practical does not mean ditching fundamental science. It means using fundamental science for a purpose, and practical problems as a stimulus to curiosity. Chemists can still be curious, en route to addressing the big societal challenges of our times. ■

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