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Editorial Open Access

Defining Chemistry in the Twenty-First Century

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Editorial

What exactly is Chemistry? In their editorial, *Let's get practical*, [1] Whitesides and Deutch address an important, related question: What is the future of Chemistry? Their assessment is that Chemistry cannot continue as a scientific discipline in its current form, and they prescribe targeted research that addresses relevant societal problems because "Chemists must remember where the money comes from". They suggest that Chemistry must be restructured and, for example, merged with Chemical Engineering at the academic level. This article provoked discussions in hallways, blogs, and email amongst chemists and, anecdotally, most people are in agreement that something must be done for chemistry to survive in a recognizable form. The prognosis of Whitesides and Deutch is dead on, however the prescription—that chemists should tear down academic disciplines and embrace change—does not go far enough in addressing the underlying problem, which is the inability of self-identified chemists to agree on a simple answer the simple question, "What is Chemistry?" The first step is for chemists to accept that Chemistry is not a scientific discipline, at least not in the traditional sense.

Chemistry began as a physical science that did not quite fit the definition of Physics. It is the study of matter, but is obsessed with affecting changes to matter at the molecular level, rather than the forces and laws that govern the changes. The intellectual peak of modern chemistry was the elucidation of the chemical bond, yet to this day it is not possible to write down a mathematical formula to describe how all but the simplest chemical reactions will proceed; only to rationalize it post facto. What propelled Chemistry beyond dyes and explosives and, arguably, defined it in the modern area, was petroleum. Plastics, pharmaceuticals, photolithography, carbon composites, coatings—the chemical roots of modern technology are widespread. Yet one of the most prolific chemists of the 20th Century, Linus Pauling, is not a chemist by modern standards. Pauling explained reactivity in terms of chemical bonds and was integral in uncovering the molecular basis of life, yet these accomplishments are readily parsed as Quantum Mechanics (as is the work of Niels Bohr, one of Pauling's mentors) and Molecular Biology in the parlance of the 21st Century. But that is precisely what makes Pauling a prototypical chemist; his accomplishments spilled over into and created new fields of science. And that is what Chemistry does; it creates.

Chemists create new molecules, new materials, uncover new phenomena, and create new problems that raise new questions. Chemists are experimentalists; if their results contradict a theory, then the theory must be wrong. When chemists unearth a problem of sufficient complexity and interest, a new field of science is created to address it. The fingerprints of Chemistry are all over Biochemistry, Molecular Biology, Materials Science, Nanotechnology, and myriad other scientific disciplines and areas of research; and modern chemists frequently work at the interface with these fields. Why, then, is it nearly impossible to satisfactorily define Chemistry? It is not merely a matter of scope, as other scientific disciplines have little trouble partitioning and grouping areas of interest. Consider Physics, Biology, Engineering, Medicine, and Mathematics; which does Chemistry have the most in common with? University Mathematics departments teach courses for and in practically every other department outside of Literature and History. Even business schools recruit instructors from math departments. Erwin Schrödinger is a famous physicist, but is arguably most famous for the mathematical equation that bears his name. Many great physicists were also brilliant mathematicians, who contributed to Mathematics in the course of using math to describe Nature. Is Mathematics a science? No, it is a language that is utilized by practically every aspect of modern civilization. Is Chemistry a science?

A remarkable quality of a pure mathematician is the ability to abstract almost any problem as math, regardless of the specific context. Chemists share this trait in the sense that so much of modern science and technology is derived from the principles of chemistry, that a chemist can usually understand—and often solve—a problem regardless of the specific context. Whitesides and Deutch identified this phenomenon as "Chemistry's strengths", listing "complex kinetics, biology and environmental networks, the 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". That is an impressive list, but the key item is "many others". In other words, Chemistry is the language of atomic matter. A proper chemical education allows one to utilize this language–and the commensurate way of thinking–in any number of the sciences. And chemical education is exactly what is at stake.

The perceived erosion in the viability of Chemistry is visible in the paucity of departments bearing the monicker "Department of Chemistry" without the inclusion of "Bio" or "Engineering". The result is the slow absorption of the teaching component of academic chemistry into other departments, though this phenomenon is arguably still more pronounced in Europe than the United States. Research efforts in Chemistry are then rolled into multidisciplinary centers and institutes, where the self-fulfilling prophecy that fewer students are interested in pursuing careers in Chemistry propagates. Eventually all that will remain is the modifier "chemical". And this problem is exacerbated by the often ossified, anachronistic thinking of traditional chemistry departments that apply purity tests to research rather than education, turning away talented chemists whose interests have strayed beyond the confines of an irrelevant and narrow definition of Chemistry. This new breed of chemists has the potential to re-define the perception of Chemistry to the next generation of chemists by broadening curricula and exposing students early on to concepts, and linking them to Chemistry. A striking example is the use of the popular scientific monickers, Energy and Nanotechnology. These words should

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immediately evoke a connection to Chemistry, but have instead found more comfort in engineering as academic chemistry is preoccupied with the line that separates "basic science" from something that is "too applied".

Parsing Chemistry as a language and way of thinking rather than a pure science is pedantic. After all, Chemistry–unlike Mathematics–cannot be confined to a chalkboard; experimental science evokes images of a laboratory full of bubbling solutions, beakers, and test tubes full of colorful liquids. In that respect, Chemistry is the archetypal experimental science. And the last time academic chemistry succumbed to the calls for change and embraced the life sciences, it lead to even more narrowly-focused departments whose purity tests suddenly had to incorporate a "bio" component to justify new hires. Worse, it blurred the line between funding for Chemistry, which was traditionally a physical science, and the life sciences, squeezing out some venerable areas of fundamental chemical research and lending credibility to the wrongheaded notion that Organic Chemistry was dead. Combined with the explosion of the scientific literature in the digital age, arguably the majority–but at least a significant part–of synthetic chemistry is stuffed into the supporting information in many journals. Indeed, the bar for reporting on the synthesis of new molecules has been substantially lowered; provided the application "worked", so goes the logic, proof of structure and purity (and often even sufficient information for reproduction) are not important. But that failure resulted precisely because of the recalcitrance of academic chemistry which, rather than seeing an impending change as an opportunity to expand, marooned interdisciplinary chemists in departments where they–students and professors alike–were no longer surrounded by the tradition and thinking of Chemistry.

Funding will forever be tied to societal need, but society recognizes the value of basic scientific research and trusts the judgment of scientists to explore and push boundaries. Without a robust and independent educational component, however, chemists may lose that trust completely and be relegated to immediate applications in other areas of science and engineering. Without a clear definition synthesis, supramolecular chemistry, surface chemistry etc., risk becoming just tools to reach an end-goal rather than a creative and exploratory endeavor. By understanding what Chemistry has become and how it fits into a modern definition of science that is rapidly antiquating traditional disciplinary boundaries, chemists can ensure that the two centuries of tradition that have forged the unique way of thinking and the role of chemists as creative forces in science will live on for centuries to come.

Reference

1. Whitesides GM, Deutch J (2011) Let's get practical. Nature 469: 21-22.