Educating the Chemists of Tomorrow: The Current State of Green Chemistry in Academia

(Written by Martin Mulvihill as a part of the public comment forum for the California Green Chemistry Initiative)

As a chemist pursuing a PhD at UC Berkeley, I am particularly interested and excited by the current discussion of Green Chemistry going on in the California Legislature. Although I have heard the phrase "green chemistry" more frequently at academic talks recently, I am not convinced that the chemists on the ground have a clear picture of what green chemistry research looks like. The 12 principles put forth by Paul Anastas and John Warner are good guiding principles to evaluate chemical processes, and I would like to review what I perceive as the current status of these ideas within the context of a chemistry education.

The principles that I do see being put into practice throughout the academic training of chemists are: *Atom Economy, Reduce Derivatives, Catalysis,* and *Inherently Safer Chemistry for Accident Prevention.* These principles are taught in undergraduate courses and practiced and discussed in undergraduate laboratories, preparing students who continue their education to practice these principles of synthetic design and chemical safety in their own research positions. I have seen a few other examples of these principles gaining traction at the graduate research level including: *Less Hazardous Chemical Syntheses* and *Safer Solvents and Auxiliaries* which are both motivated by chemists desire to reduce health and safety risks in the lab and also labs increasingly taking into account the design of synthetic methods for *Energy Efficiency*. I know of a limited number of labs around the country working on promoting the *Use of Renewable Feedstocks*, *Designing Chemicals for Degradation,* and *Real-Time Analysis for Pollution Prevention.*

This is good news, for the prospects of incorporating green chemical design into industrial applications, but there is still room for improvement. Most immediately work needs to be done to promote *Waste Prevention* as part of experimental design, and a serious effort needs to commence to encourage the education and research around the *Design of Safer Chemicals.* The basics of chemical toxicology are not taught at any point during the training of chemists not at the undergraduate level and not even offered in chemistry departments at the graduate level. This is not to say that chemists don't know how and when to work with dangerous chemicals, but this knowledge is gained through laboratory experience, and not formally taught. This also means that the design of new chemicals with important industrial applications rarely, if ever, takes into account the idea that chemical products should be designed to minimize their toxicity. Part of the reason for this knowledge gap is the complexity of biochemical interactions, and the current lack of easy to understand guiding principles to teach at an undergraduate level. This means that if we want to require safer products to be introduced to the market, we need to start by incorporating toxicology into the formal training of chemists, and also invest in toxicology research which could be of fundamental interest to chemists.

All twelve of these guiding principles can be incorporated into chemistry research, but their assimilation into basic chemical knowledge is a hierarchical process. It starts at the research stage, where through targeted funding and positive press, new knowledge, procedures, and products are developed. Then, as the ideas become accepted and followed by the research community they will be adopted as part of the graduate level curriculum. Lastly as chemists come to believe that this is how chemistry has always been done it will be adopted as part of the core values/ideas that are taught to undergraduates in chemistry. Although this can be a lengthy process, research funding and legislative pressure on the chemical industry certainly has the power to accelerate the adoption of these ideas by the chemical community. The problem that is in dire need of funding and support is the incorporation of toxicology into the research and training regimen of chemistry students. Also in need of further support are those ideas which are still on the fringes of research and teaching including *Use of Renewable Feedstocks Designing Chemicals for Degradation, Waste Prevention* and *Real-Time Analysis for Pollution Prevention.* Industrial chemicals and chemical processes are increasingly a part of our daily life, and as we have seen in Europe the public is demanding higher standards. California has the intellectual resources to lead the way if the proper investments are made.

Sincerely,

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