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Teaching chemical product design

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ABSTRACT

The chemical industry today includes both commodity products and higher value-added products. While the design of commodities is dominated by the process costs, higher value-added products also depend on product design, including discovery, product selection, and time-to-market. Chemical engineering education has sensibly begun to change toward courses on both process and product design. However, while there is an emerging consensus that these changes should take place, there is no clear agreement on what the changes should be. Moreover, these new directions are very difficult to teach, at least in the current environment. This paper will discuss different efforts to incorporate product design into the chemical engineering curriculum and different successes in doing so. However, while the value of including this material seems unquestioned, the way in which it is best taught is unclear.

1. The current chemical industry

Unlike the hopes expressed by some industrial leaders, the chemical business is not a growth business. It was a growth business 50 years ago, when the manufacturers of textile fibers changed the clothes that were on the backs of all the peoples in the world. At that time, the chemical business had growth rates that were comparable with the electronic business of today. That clearly is no longer the case. Over at least last 25 years, the chemical industry has been a commodity business, using hydrocarbon feedstocks obtained from less developed, frequently unstable areas. As a result, chemical corporate planning has become extremely difficult.

One result was that the chemical business went into a period of contraction. Larger chemical companies began selling off their commodity products. The Dupont Company sold nylon, its signature product, to Koch for $4.4 billion. General Electric sold its plastics business to Sabic. Dow Chemical tried to sell most of its commodity chemical business to the Kuwaitis. One month after they had signed the contract with Dow, the Kuwaitis decided they had made a bad deal, and paid over a billion dollars to extricate themselves from their contract. These are not signs of a growth business.

And then came fracking.

Fracking is a technique of horizontal drilling underground. Developed over 50 years ago as a means of enhancing production of conventional wells, fracking in its modern incarnation involves not only horizontal drilling, but subterranean explosions to open reservoir formations. When these formations are opened, they then are subjected to high pressure injections of aqueous suspensions which include sand. The grains of sand prop cracks in the formation open, allowing petroleum liquids and natural gas to be harvested. This increased production of natural gas has caused natural gas prices to drop almost in half, giving the chemical commodity business in developed countries has a new lease on life.

Now, the chemical business is undergoing a major renaissance. The resulting changes are magnified because the business had anticipated a static market, at least within the developed world. The business had been cutting back on hires, so that the average age of the employees was much greater than it had been historically. In some cases, more than half of the company employees were retirement eligible. The cheaper

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natural gas suddenly changed the industries' goals. If they now plan to make commodities, they will need to hire younger people. Thus there will be new jobs for engineers to work on commodities.

But at the same time, many chemical companies believe that in the long term they have a more significant opportunity in products other than commodities (Cussler and Moggridge, 2011; Wesselingh et al., 2007; Wei, 2007; Teixeira et al., 2013; Moggridge et al., 2006). The reason is simple: non-commodity products can have significantly higher added value. Corporations planning new products will also need new people, so there will be a second market for engineers to work on non-commodity products. While the relative size of commodity and non-commodity employment markets is unknown, many expect the numbers in the two areas to be roughly comparable. This altered product mix was recognized in 2005 by the European Federation of Chemical Engineering (EFCE) with the statement:

> "While all chemical engineers still need much of the traditional skills, the European Federation of Chemical Engineering feels there is now a need to include some knowledge of "product engineering" in the common core".

Thus we faculty need to think of educating our students for both these business areas. How we do so for non-commodity products is the subject of this article.

2. Thinking about chemical products

Some think that the design of chemical products should not be that different than the design of chemical processes. This is not true (Ulrich and Eppinger, 2008). As an illustration, consider the products shown in Table 1, products that we have been asked about in the last few years. Polypropylene, sulfuric acid, and oxygen are chemical products. In each case, the processes by which these are made are the key to their development. But there are many other chemical products in Table 1 that will require different development. Three examples are shown in boldface in the table. With smart labels, we could label a package of chicken to track the age and the temperature history of the chicken. On our homes, we could install solar shingles which not only protect the house but generate electricity on the sunny days. We could seek textiles which feel silky but which are made from completely different materials than from silk. Each of these topics—smart labels, solar shingles, and silky textiles—is a chemical product, but the way in which they are developed is different than the ways by which processes are developed processes for spinning nylon or synthesizing titanium dioxide.

Table 1 – What will future products be? To think about this, make a list of potential products, and decide how their amounts and values change which aspects are important.

Polypropylene	Nylon
Petrol	Vanillin from black liquor
Smart labels	Light emitting diodes
Biofuels from biomass	CO_2 capture
Sulfuric acid	**Solar shingles**
Thermopane windows	Freon-free foam
Oxygen	Perfume engineering
TiO_2	Epoxy resins
Silky textiles	Penicillin

Table 2 – How to think about future products to explore this, we suggest that you define a fourth category, and identify its characteristics.

	Commodities	Molecules	Microstructures
Key	Cost	Speed	Function
Basis	Unit operations	Chemistry	Microstructure
Risk	Feedstock	Discovery	Science

Once we recognize this group of products, we need a way of thinking systematically about these. One way, described in Teixeira et al. (2013), is to group them under three categories, as listed in Table 2. Other product classifications can also be valuable, but we can do better if we organize our thinking around categories. If you have already taught product design, we invite you to skip to the next section. If you have not taught product design, you may wish to read the following summary about product categories.

The three categories of products are commodities, molecules, and microstructures. The way in which these three categories of chemical products are developed is different. Commodities are the most familiar, because their development depends so strongly on cost. Profit margins for commodities are small, so low cost processing is an axiom of classical chemical engineering ideas. Small profit margins are the why the commodity chemical business has been threatened by having feedstocks from less stable, less developed countries.

The familiar process engineering, which is essential to commodity chemicals, is much less important for molecular

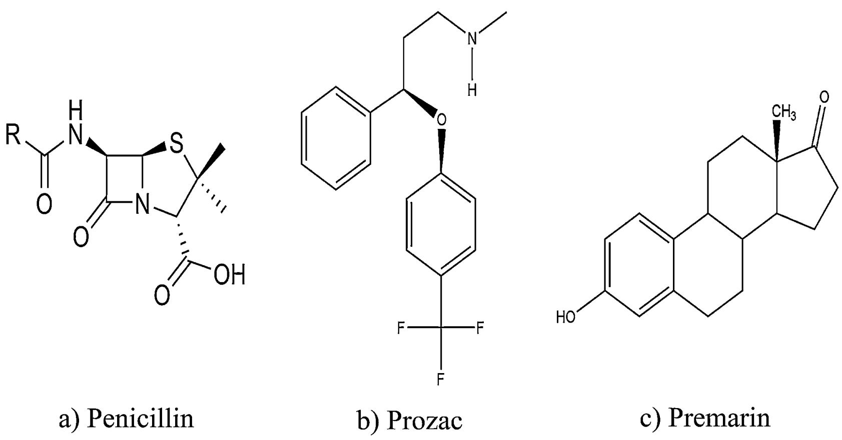

Fig. 1 – Three molecular products. The discovery of these products is more important than the process by which they are made.