What Should Be Taught By The Engineer?

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Ideally, the teaching of Materials Science or Engineering Materials by engineers is unnecessary but in the same sense that all of engineering is unnecessary. Engineering has been defined in many ways, but the essential features of any definition generally incorporate some words dealing with the laws of nature, economics, the benefit of mankind and judgment. Materials obey certain physical laws, economics is involved in their use, benefits are derived from their use, and judgments have to be made in their use so, by definition then, Materials does fall within the scope of engineering. Given conditions where the laws of nature are known, economics is fully understood, and the benefits to mankind are clearly evident, there is not much left to the exercising of judgment, and the need for engineers would disappear. This is not likely to happen in the foreseeable future, so we can dismiss the ideal case and get to the case at point.

If engineering consists of a mixture of mathematics, science, economics, utilitarian ends and judgments, can't this be simply broken into its component parts, be taught by specialists, and then be brought together to produce engineers? The answer is that this is essentially what we do in our various engineering curriculums. The mathematics and sciences are taught in the early years, their economic application, the development of judgment in making alternate choices occur later in the programs. In terms of ECPD accreditation, the sciences, engineering sciences, then the analysis, syntheses and design.

Where does Engineering Materials fit in these curriculums? Not in the early years with the sciences since it is not a science, but an engineering science. It is different from the usual engineering sciences in that instead of being based only on physics, is also based on chemistry. It is this dual base that causes so much difficulty in teaching Engineering Materials. Most engineers, with the exception of the Chemical, Metallurgical and Ceramic groups, elect only one year of chemistry while the chemistry that is needed is Physical Chemistry and this, in most schools, is not a first year chemistry course. The Chemical Engineers then as a group have a decided advantage over most other engineers in that they have the science base on which a good materials course can be taught. A further advantage in most chemical engineering curriculums is that they invariably have course work on Thermodynamics and Rate Operations and both of these courses provide an additional set of foundations for the materials course work.

Given then a person with training in mathematics, physics, chemistry, thermodynamics, possibly rate-operations, and engineering science training in mechanics and strength of materials, it isn't a particularly difficult task to put together a Materials Science or Engineering Materials course that has real depth and meaningfulness.

One of the first things to be done before discussing what to teach chemical engineers is to determine the scope of the materials field. To many engineers the word materials means the selection of a substance for a particular application. To an electrical engineer it is the electronic properties of conduction, semi-conduction, insulating or magnetic properties. To a mechanical engineer it is a structural material with the emphasis on the elastic, plastic or shock resistance. To chemical engineers it is a structural material but subjected to corrosive environments. So it goes on down to a civil engineer to whom materials means concrete, asphalt and reinforcing bars. These engineers are primarily concerned with the specification of materials for various end uses.

Another group of engineers, equally as large or even larger, are interested in the manufacture and production of materials. These are primarily chemical, metallurgical and ceramic engineers whose principal concern is to prepare or take given raw materials and to convert these into intermediate products which are to later appear in some finished form. Steel, petroleum, plastics, textiles, paints, cements, solvents, etc., are but a few of what might be termed the materials industries but are more commonly known as the chemical industries.

A third group, usually chemical, metallurgical or mechanical engineers, are concerned with taking materials in bulk form and in fabricating them to finished shapes for direct use by other engineers. Casting, extruding, forming, blending, treating and in general processing them for ultimate use.

These last two groups, in addition to knowing enough about materials to specify them for use, must also know how to manufacture, process and treat these materials so they will have the required properties for ultimate usage. This is a much more severe requirement than simply knowing what the ultimate properties are, and as you will note, chemical engineers are predominantly active in these second and third groups. It is for this reason that I believe that the materials book given to a chemical, metallurgical or materials engineer should be pitched to a higher level than one would give to civil, electrical or mechanical engineer. These other fields would certainly profit from a more intensive treatment of materials science, but their lack of preparation, principally in chemistry and thermodynamics, makes this an extremely difficult teaching assignment.

What should chemical engineers be taught about materials? My viewpoint is that they should be taught from as basic a standpoint as is practicable with a view to understanding why materials have certain properties, rather than attempting to teach them how to produce, process or specify materials. Knowing the why, one can usually deduce the how, while the converseis not true. One occasionally gets into arguments with scientists about this point. Some feel that it is their job to teach the why, and the engineers' job to teach the how. This may have been true in some cases in the past but is not true of many engineering fields today. There are differences, of course, between scientists and engineers but the teaching of why's and how's is not the distinguishing feature. To me, the principal difference between the two is this: a scientist generalizes while an engineer must particularize. Solid state physicists are quite content with order-of-magnitude agreement between theory and fact, and chemists are practically always concerned with thermodynamic equilibrium. As engineers, however, we can't design processes to orders of magnitude and we are more concerned with kinetics or the rate of approach to equilibrium than we are with where it is. True, we need the science to tell where we are going, but how we get there is our problem. There is a vast difference between knowing about materials from a physics and chemistry standpoint and knowing about them from an engineering standpoint. We must be familiar with the sciences but the scientists can and do get along very well without the engineering.

Materials have a chemical constitution and therefore chemistry is certainly important. They do exist in various environments: electrical, magnetic, mechanical and thermal fields, and they will obey certain physical laws, therefore, physics is important. If crystalline, structure is important; if non-crystalline, the degree of lack of structure is important, etc. It is quite fruitless to argue which is the more important since if they yield useful information, the engineer can use them; maybe not in the way the scientists think they should be used, but nevertheless, he uses them. Another way of stating this I heard from the late G.G. Brown: "A scientist is one who solves the problems he can solve while an engineer is one who solves the problems he must solve." This is certainly true in regard to the materials field. The physicists work almost entirely in those fields where properties are determined by electrons such as conduction, semi-conduction and magnetism. Chemists are a little broader and more apt to be experimentalists, but their efforts are more along the lines of analysis, studies of non-stoichiometry, phase equilibria, etc. Important studies it is true, but not important to the engineer until they become useful.

The principal reason then engineers should teach materials science is that they are in a better position to judge what are the useful parts of the various sciences that are applicable to this field. For example, many materials are classified as crystalline solids, therefore a knowledge of crystallography is necessary. The whole load such as one would get in a typical two-course sequence in Mineralogy or Geology? Obviously not. There is nothing wrong with these elections; one can even make a strong case for such a program. It is just that there are large portions of this work that are of no direct usefulness, now or in the near future, for the engineer. The parts we need, we need badly but not to the extent that we would elect the entire package. Since crystallographers are usually adamant about modifying the existing course we extract the applicable parts and teach it ourselves. This same extractive operation is carried out on various portions of chemistry, physics, and even engineering courses, to yield a body of information which can be called materials science.

Chemical engineering students certainly obtain a surfeit of thermodynamics in their training. It occurs in the early heat and material balance courses, in the physical chemistry, in the regular chemical engineering thermodynamics courses. The difficulty in using this in materials science instruction is that for the most part all this prior work is in the liquid or gaseous state, and the student has to be shown its applicability to the solid state. The extensive training most engineers receive in engineering mechanics has to be reoriented from the macroscopic scale to the microscopic. In many respects a course in materials science consists in nothing more than taking material previously presented in a different context and reorienting it, adding new application information and welding the mixture into an engineering course. To insist, as many scientists do, that this can't be done is to deny reality. It's done because it has to be done. We can't afford the time for the unhurried, comprehensive, historical, and rigorous approach that they insist upon. The fields of metallurgical and ceramic engineering are two which were formed largely because they did not constitute a respectable part of either chemistry or physics since their subject matter didn't obey the rules. Because of industrial and engineering pressures for improved materials of these types, they became engineering disciplines and were forced to develop their own science along with the engineering applications. Their success in accomplishing this is largely responsible for the current enthusiasm of solid state physicists and chemists for working in these fields.

As in all engineering courses, the syllabus of a course on materials science for chemical engineers changes from semester to semester as new developments occur. Of the order of one-half of the material doesn't change and this is the basic science. Topics such as atomic and molecular structure, crystallography, phase equilibria, thermodynamics, kinetics, bonding and electron theory make up the bulk of this material. The teaching of this material does not introduce any new material to the chemical engineer; he has touched on much of this in several courses in physics, chemistry and engineering. The transition from the macroscopic to the microscopic scale in elasticity and plasticity and the introduction to lattice defects opens up the whole concept of defect structures which is so important to the understanding of many solid state phenomena. The extension of electron theory to zone theory and the concept of electronic defects leads to electrical and magnetic phenomena. Having discussed the influence of electrical, thermal, magnetic and stress fields on solids, it's an easy step then to discuss the tensorial relationships between these to pick up the cross-effects such as thermoelectricity, piezoelectricity, magnetostriction, etc. In the development of this work the emphasis is always on the usefulness relative to engineering with engineering applications stressed wherever possible.

More recently emphasis has shifted towards the structure of liquids and its applicability to polymeric materials and amorphous materials such as the glasses. An area which is fast developing is that of surface phemomena. Its relevance to engineering problems in oxidation, corrosion, catalytic activity, lubrication, wear, etc., are treated although this subject matter is nowhere near as well developed a body of information as the bulk properties, yet it is probably of more immediate significance to the engineer than the bulk properties.

You will note from this brief description of the course that is taught to chemical engineers that this is not a course in how to specify materials, how to make them or how to process them. It is aimed instead at trying to understand why they have certain properties and why processing or treating them can modify these properties. Subsequent course work builds on this course and deals more specifically with metals, ceramics, plastics, etc. While I see no reason why this course could not be taught by non-engineers, it is my feeling that in order to bridge the gap between the science and the engineering it would take someone with an engineering background since the principal gain is to engineering, not to science.