KNOWLEDGE STRUCTURE OF THE STOICHIOMETRY COURSE

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Most chemical engineering curricula in North America begin with the stoichiometry course. The content of this course is fairly standard: definitions, measurement, and estimation of various process variables and physical properties of process materials; descriptions and flow charts of unit operations and integrated processes; gas laws and phase equilibrium relations; laws of conservation of mass and energy; and the incorporation of all of the above into material and energy balance calculations on individual chemical process units and multiunit processes. The material is not intrinsically difficult, especially compared to the content of later courses in transport processes and thermodynamics, but the approach required to set up and solve course problems takes most students considerable time to grasp.[1]

The course may conveniently be divided into two parts for the purposes of defining a knowledge structure—material balances and energy balances. Possible structures for each part are shown in Figures 1 and 2: The following paragraphs comment on those structures.

Knowledge Structure
Material Balances
(Figure 1)

• The concept of conservation is essential to the course and is generally accepted implicitly. The principal concepts that all students must bring with them from their prior education come from mathematics (basic algebraic and graphical manipulations, solving sets of linear equations and word problems), physics (phases of matter, conservation of mass), and chemistry (atoms and molecules, stoichiometric equations, molecular weight, and molar quantities).

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• The building blocks of the course are properties of process systems and materials including mass, volume, pressure, temperature, and (later) energy. These properties are conceptually taken for granted in the course, although both professors and students might be hard pressed to define most of them. Fortunately, they are familiar enough for us to be comfortable with them, which is all we need to be able to build on them successfully.

• Other broad concepts that may be presented in first-year courses but are more likely introduced in this one include (a) multistep chemical processing and graphical representation of chemical processes (flowcharts); (b) the idea that a system has a *state,* defined as the collection of all its physical properties and determined by the values of a subset of those properties; (c) various physical laws and relations among system variables that allow some variable values to be determined from specified values of others; (d) the notions of equilibrium, dynamic equilibrium, phase equilibrium, reaction equilibrium, and steady-state and transient operation of a system; (e) the idea that variables must sometimes be estimated approximately rather than calculated to six significant figures; (f) the idea that problems must sometimes be solved by trial-and-error; (g) the idea that there's nothing illegal or shameful about (e) and (0.

Most of the content of this part of the course consists of definitions of and relations among the variables that characterize chemical process systems—temperature, pressure, volume, density, flow rate, mass fractions and concentrations, fractional conversion, compressibility factor, vapor pressure, relative humidity, etc.—and procedural and computational algorithms for calculating values of some of these variables from known values of others. The sequence of the information flow is suggested in Figure 1.

Knowledge Structure
Energy Balances
(Figure 2)

All of the material listed in the previous section is prerequisite to that which follows.

• Energy now takes its place as a basic course concept that few involved with the course either understand or question. Again, the fact that we think we know what it is

and feel comfortable about it keeps us from hopelessly bogging down at this point.

- The integral of a function now joins the list of prerequisite mathematical concepts and the principle of conservation of energy joins the required physical concepts.

- Once energy and temperature are admitted as working concepts, the three forms of energy (kinetic, potential, and internal) and modes of energy transfer (heat and work) can be introduced, setting the stage for the **first law of thermodynamics**.
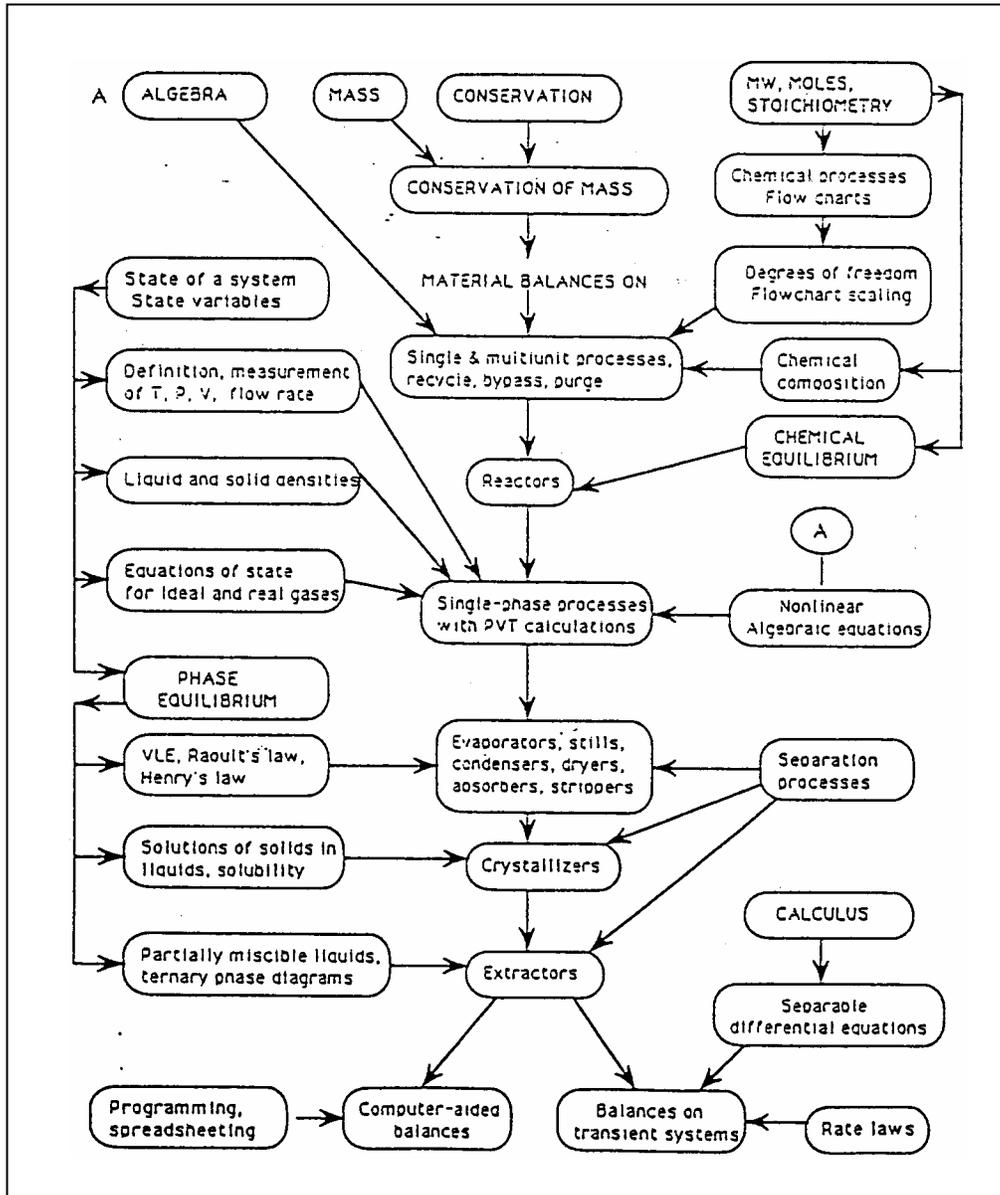

Figure 1. Knowledge structure—material balances

A concept that arises in the context of the first law is **enthalpy**, defined for convenience as a frequently occurring combination of other system variables ($H = U + PV$). Perhaps because of its strange-sounding name, students never get fully comfortable with enthalpy—they eventually learn to work with it (as in $Q = \Delta H$), but they always have the feeling that there is something fundamental and mysterious about it that puts it beyond their intellectual reach. Trying to convince them that enthalpy is really a simple concept and that things like mass and energy are concepts much more worth worrying about is generally futile. (Later they will get into thermodynamics, which will finish the job of overwhelming them with variables defined for convenience and given strange names.)

o   The previously introduced notions of the state of a system and state properties now reappear, leading to the concepts of reference states and process paths for calculating ΔU and ΔH. All the necessary ingredients for energy balance calculations are now in place.
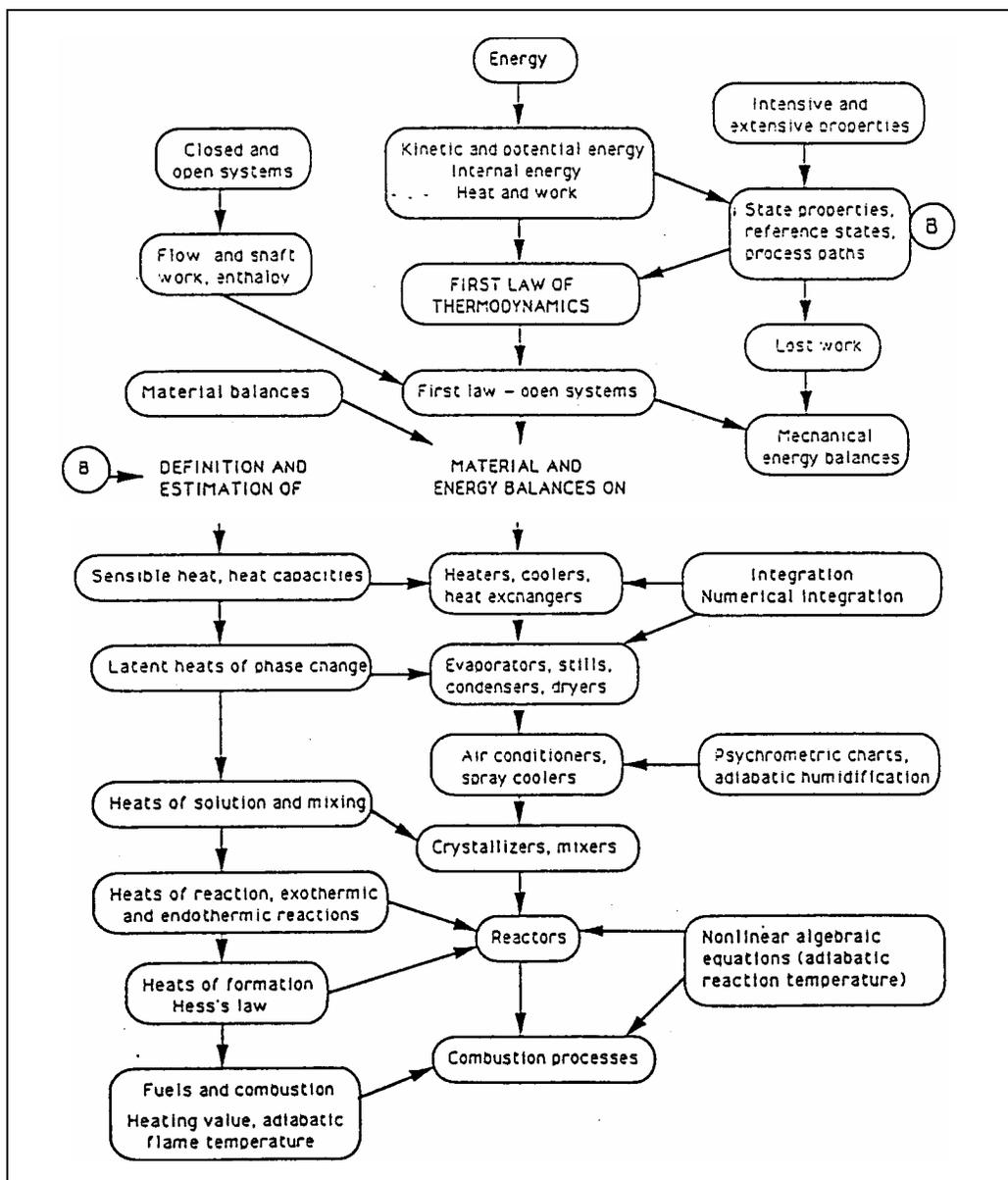

Figure 2. Knowledge structure—energy balances.

- Most of the content of this part of the course consists of (a) definitions of and procedures for measuring and estimating the energy-related variables that characterize chemical process systems— heat capacities, latent heats of phase change, solution, and mixing, and heats of reaction, formation, and combustion; (b) procedural and computational algorithms for calculating internal energy and enthalpy changes associated with transitions from one system state to another; and (c) procedures for solving the first law equation for unknown energy flows or changes in state in various unit processes. The sequence of the information flow is suggested in Figure 2.

TRANSIENT BALANCES

Most stoichiometry textbooks contain a chapter on transient system balances. A key concept here is that of a derivative. While students in the course can differentiate functions on demand, they have no physical or intuitive understanding of derivatives, in part because most mathematics professors seem to fear that they would harm their reputations by putting applications in the elementary calculus sequence. Covering transient balances in the stoichiometry course could help the students make significant progress toward this understanding; unfortunately, the course almost never gets to transient balances and most introductory transport courses take the underlying knowledge structure of this topic for granted.

AFTERWORD

Once a knowledge structure has been defined, the next logical step is to consider how it can best be transferred into students' brains. I believe that for stoichiometry there are two keys:

1. *Provide explicit instruction and lots of drill in basic problem-solving procedures,* especially the systematic use of the flow chart coupled with informal degree-of-freedom analysis to organize the solutions of material and energy balance problems.

2. *Establish an active, cooperative learning environment.* Have students work in teams on problems in class and on the homework, identifying conceptual and procedural sticking points and finding out how to get past them, teaching and learning from one another.

For specific ideas about how to accomplish these tasks, see Reference 1.

REFERENCES

1. Felder, R.M, "Stoichiometry Without Tears," *Chem Engr. Ed..* 24(4), 188 (1990).