TEACHING UNDERGRADUATE MASS AND ENERGY BALANCES-1972 +

DONALD R. WOODS
McMaster University
Hamilton, Canada. L8S 4L7.

GARY F. BENNETT
The University of Toledo
Toledo, Ohio 43606

G. MICHAEL HOWARD
University of Connecticut
Storrs, Conn. 06268

MICHAEL J. GLUCKMAN
The City College of New York
New York, N. Y. 10031

New needs, new challenges, new outlooks, new knowledge—these keep the engineering curriculum in a state of flux. The Education Projects and the Undergraduate Education subcommittees of the AIChE decided to bring together all those interested in the teaching of one particular subject to share experience, and to identify new trends and new needs.

A questionnaire was sent to all Chemical Engineering Departments in United States and Canada in June, 1972. Sessions were held at the New York AIChE meeting November 1972 and at the Vancouver meeting in August 1973. The response to the questionnaire was overwhelming and extremely interesting; the conference get-together was very well-received. We realize that studying a course out of the context of a complete program can be very misleading. The specific objectives, prerequisites, the other courses in the program and the staff and facilities available are unique to any program at one particular department. Nevertheless, despite these complications, it is useful to provide a snap shot view of the teaching of Undergraduate Mass and Energy Balance—1972 and some hints of future trends. We hope this is but a start of a series of critical summaries of the courses in our educational program. Mass and Energy balances is to many students their introduction to Chemical Engineering. What are the characteristics of today's students? What are the content-objectives of the course? Is the lecture technique universally used? What do instructor's believe are the major challenges? and What about the future?—these are some questions we try to answer.

THE CHARACTERISTICS OF THE STUDENTS

It is difficult, and perhaps even dangerous, to attempt to generalize about the nature of students in their sophomore year. However, we think that it is very useful to at least try to characterize the "consumers" to whom this course is presented. Some characteristics are:

- **The majority of the courses they have taken have been in the sciences to broaden their knowledge of fundamental principles of physics, chemistry and mathematics.**
- **They are used to more or less memorizing "cook book" methods of solving problems.**
- **They are not used to open-ended problems, ill-defined problems requiring assumptions or problems where there are a number of "good" answers.**
- **They are not accustomed to the law of optimum sloppiness, or to doing "sloppy" order-of-magnitude calculations, or to the principle of successive approximation.**
- **They know very little about engineering hardware and about the chemical engineering profession but are very anxious to learn about these.**
- **In the early 1970's a prime concern is the relevancy of the material and of the profession. They are less willing to gain knowledge because we instructors say they need it. They want to, and almost demand, to be told why they are learning it and its potential application. They want to be "turned on".**
- **They believe they have well polished logical thinking and debating skills. Yet, for many these skills could be improved greatly.**
- **In particular for the traditional content in mass and energy balances, they believe that they know much of the material already.**

Developing a single course to meet these diverse backgrounds, interests, and needs poses a challenge for even the most skilled teacher. A summary of these challenges is presented later.

CONTENT-OBJECTIVES

In general, the central themes of this course

Gary F. Bennett is a graduate of Queen's University and the University of Michigan (Ph.D.). He is head of the University of Toledo's Biochemical Engineering Laboratory and director of environmental programs for their adult and continuing education division. His honors include designation as 'Outstanding Young ChE of the Year" and "ChE of the Year" by the Toledo Junior Chamber of Commerce. His teaching and research interests are in the areas of water pollution and biomedical engineering. (ABOVE LEFT)

D. R. Woods is Chairman of the Shared Teaching Experience subcommittee. He is presently developing a course to teach problem solving skills. His teaching interests are in process analysis, information management and cost analysis. The separation of oil-water systems and surface phenomena are his research interests. (ABOVE RIGHT)

Dr. Gluckman is an Assistant Professor in the Chemical Engineering Department at The City College of the City University of New York. Prior to joining The City College he worked for ten years as a Senior Process Design Engineer for the St. Regis Paper Company. Dr. Gluckman received the B.Ch.E. degree in 1958 from the University of Cape Town, South Africa, and a Ph.D. (Chemical Engineering) from the City University of New York in 1971. (NOT PICTURED)

G. Michael Howard is an Associate Professor of Chemical Engineering at the University of Connecticut. His main teaching interest recently has been the development of a general first course for all freshman engineers. He has taught courses in process dynamics and control, transfer operations, applied mathematics, and the ChE Laboratory. His research interests are in the general area of process modeling, simulation, and control. He holds degrees from Rochester, Yale, and Connecticut and has a variety of industrial experience.

are: developing problem solving ability, learning and applying the principles of conservation of mass, and learning and applying the principles of conservation of energy. Associated with these is the need for a set of units of measurement and a unit system, some basic laws about the behaviour of liquids and solids (physical and thermal properties and concepts), some mathematical skills, and some skill in communicating the results of engineering work. These associated needs can become a major focus of the course or they can be minimized to the extent that some of them are deleted entirely.

Other objectives usually include learning attitudes and manual skills. Bloom et al (1954) and Krathwohl et al (1964) classify the intellectual and attitudinal learning regions. Development of a professional attitude is considered to be important. Some professional concepts are listed in Table 1. The course tries to show what professionals do and to generate an appreciation of their role in society both now and in the future. This includes motivation of the students toward a professional career and the establishment of personal goals within the profession.

Some manual skills that some feel should be

TABLE 1: Some Affective Domain Concepts Important to Chemical Engineers (levels 1 to 5)

USE OF ALL RESOURCES:
- What products and services are useful and needed by mankind?
- Does this represent the optimum long term use of natural resource resources?
- Sense of urgency of man's needs.
- Willingness to compromise theory with reality in satisfying man's needs.

VALUES OF HUMAN WORTH: plant safety, safe products, salary and job security, human relations and effect of present operations and products on future health of society.

ESTHETIC VALUES

MORAL AND ETHIC VALUES
- micro and macroscale
- —employment (seeking and hiring and firing those working for you)
- —environment
- —use of natural resources
- —use of intellectual human talent
- —information
- —honesty

INTERACTION WITH OTHER PROFESSIONALS
- Willingness to actively participate in professional organization.
- Loyalty to colleagues
- Confidence in one's own abilities
- Initiative to start programs on one's own maturity in outlook Reliability

learned include experimental techniques (such as ability to titrate, use a balance, make a thermocouple, to run equipment, to set up bench scale equipment) and skills in keypunching or patching together an analog computer.

The course is actually taught in many different ways as illustrated in Figure 1. These include integrated throughout the program with no course *per se;* as part of a thermodynamics course; with the emphasis on career guidance and professional responsibility, on stagewise processing, on solving several large case problems, on synthesis, on analysis or problem solving, on mathematical methods, techniques and/or simulation, on mass and energy balances, or on computer programming and systems. Most courses are mixtures of these approaches, and these are not mutually exclusive.

The textbooks and resources used are often indicative of the emphasis in the course. Texts that emphasize the conservation concepts include Anderson and Wenzel (1961), Himmelblau (1967), Hougen, Watson and Ragatz (1954), Ranz (1970), Schmidt and List (1962), Thatcher (1962), Tyner (1960) and Williams and Johnson (1971). Whitwell and Toner (1969) emphasize problem-solving. Henley and Bieber (1959), Henley and Rosen (1969), Blum (1971) and Dorf (1969) have a more mathematical bent. Meissner (1971), Shreve (1967), Stephenson (1966), Wendland (1971) and Thatcher (1962) are career and process oriented. Henley and Staffin (1963), King (1971) and Brian (1972) are used as texts by some to introduce processing equipment. The thermodynamics texts used are Balzhiser, Samuels and Eliassen (1971), Denbigh (1971), Smith and van Ness (1959), Sonntag and van Wylen (1971) and Wales (1970).

Over forty schools indicated that they were using Himmelblau's book. Whitwell and Toner, Schmidt and List, and Hougen, Watson and Ragatz were all used by more than five schools. More interesting is the fact that twenty five professors are using a very new book on their own notes in teaching this course.

Some outstanding new textbooks on the market that offer the opportunity to emphasize the areas illustrated in Fig. 1 are:

- **Rudd, Powers, Siirola (1972) "Process Synthesis". Choice of cases exceptionally good; illustrates breadth of Chemical Engineering and the general universality of the principles they present. Identifies steps in synthesis as reaction path synthesis, material balancing and species allocation, (review of separation technology) strategy for selecting separation task equipment, energy balances and task integration. Each step is abundantly illustrated via case examples from extremely diverse examples. Finally, two cases (fresh water from brine via freezing and detergents from petroleum) are discussed to illustrate synthesis as one large integrated operation.**

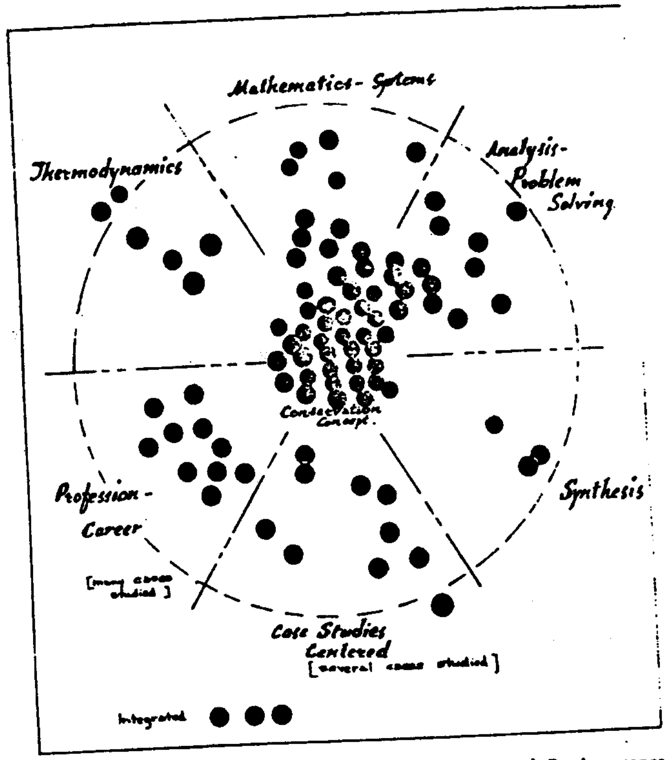

FIGURE 1—Classification of Approaches Taken. Central Region represents emphasis on mass and energy conservation concepts.

- **Russell and Denn (1970) "Introduction to Chemical Engineering Analysis". Formulation and problem solving are major themes. Introduces rate concepts. Interrelates experiments, modeling and application.**
- **Myers and Sieder (1972) "Chemical Process Logic". Systems approach with emphasis on mathematics, the use of the computer, solutions of sets of equations and the use of modular executive programs. Good review of mathematical techniques. Well organized and a good attempt to introduce ideas of process equipment.**

While these may not suit one's particular objectives, they open up additional resources to us as instructors and provide exciting new trends for thought.

The case study approach attracts a number of professors. In this approach, an example of a process or a case problem is studied as a means of learning concepts through a "need-to-know" or in providing synthesis experience or to motivate the students via relevant problems that also illustrate professional responsibility. A wide variety of background case information is available; see Sherwood (1963); Bodman (1968); King (1971);

Smith (1967 ff). While the majority of these cases have been used for senior and graduate level design courses, nevertheless this provides background information that can be adapted to the second year purposes. (Seagrave's (1971) first four chapters provide interesting examples of mass and energy balances in biomedical applications.) Some cases used by Pappano at West Virginia in the mass and energy balance course and the corresponding objectives are:

Natural gas: alternative uses Reverse osmosis for plating wastes	To introduce "need-to-know" physical and chemical reaction material balances, conservation of resources and minimum cost criteria.
Cryogenic liquefaction of methane ethane Gas storage	To introduce "need-to-know" ideal gas law, work in gas phase, first law and process trade off.
Separation of a liquefied methane ethane mixture	To introduce "need-to-know" vapor pressure, Raoult's Law.

Rudd, Powers, and Siirola (1972) provide a fantastically broad spectrum of case examples and case problems to which anyone seeking to locate sparkling examples to intrigue freshmen or for examples in the mass and energy balance course is referred.

It is interesting to note the differences between Pappano and Rudd et al in the approach to offering synthesis experience. Pappano uses a number of cases each of which is solved applying all the steps in the synthesis. Rudd, Powers and Siirola (1972) illustrate each step. Later, they consider several cases in detail.

In general, the course is offered after 30 weeks of university training with about 45 hours of lecture time. Some schools use tutorial time only. The experimental laboratory has almost disappeared from the United States schools although the Canadian schools still seem to favor this experience.

THE LEARNING ENVIRONMENT

Traditionally the lecture mode has been used extensively in universities. For engineering, many experimental laboratories have been popular. For developing solving skill, traditionally we have required the students to work many problems for homework. However, with the availability of a variety of well written texts, movie films and film loops, slide-tape or cassettes, programmed texts and with the relatively small classes, many other options are available for us to use. The learning environments can be classified as:

Human-sender centered: lecture, sender directed problem solving, some tutorial/discussion environments,
Learner centered: homework, games, student centered discussion, some tutorial/discussion environments,
Mechanical-sender centered: computer aided instruction, programmed texts, self-paced audio-visual or texts
Object centered: plant tours, experiments, demonstrations

Some learning environments are in between the centers. For example, the discussion, tutorial and recitation usually lie between the human sender center and the learner centered. The discussion is extremely flexible and can range from learner group discussion, guided learner group discussion, the guided problem-solving and guided synthesis to lecturer-directed discussion. Links exist between other centers where the professor is available as an extra resource to a programmed text. MacKenzie et al (1970) p. 32 point out that from a learner's viewpoint, what matters most is not the formal instruction he is given but the kind of learning resources to which he has access.

The variety of learning environment include lectures; demonstrations; student laboratories; individual or group homework problems; self-learning with textbook or printed notes, slide-tapes, films, TV tapes, programmed text, via computer simulations—interaction, and audio plus text; student-centered discussion; student-prepared lectures or reports; sender-directed problem solving or discussion; individual problems solved with discussion and games. Some indication of the mix of these environments is shown in Fig. 2 but this does not do justice to the wide variety of extremely interesting resources that are being used: plant tours oriented toward case projects,

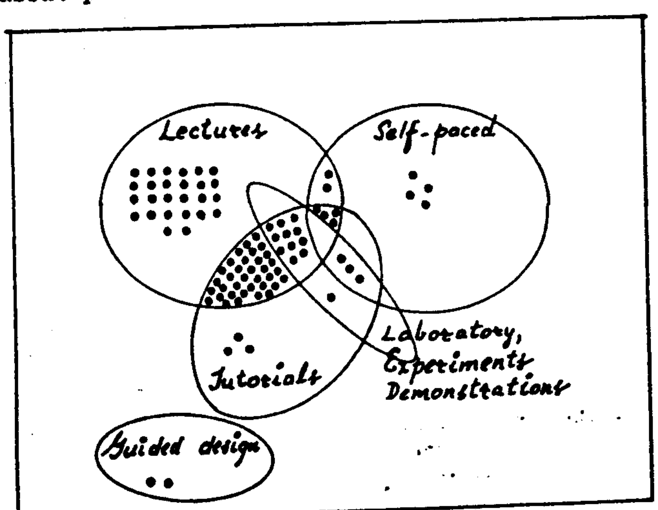

FIGURE 2—Learning Enxironment used by Respondents.

film loops, programmed texts [Wales (1970)], audio-visual packages and self-paced notes. Of particular interest is the sender-directed problem solving approach of Treybal at New York University and the guided design approach of Pappano. Many are getting away from the lecture and are using the time for discussion or group problem solving.

Self-paced programs have been developed by many in an attempt to overcome the motivational and boredom problems faced when all the class must proceed at the same pace. This has not been without its problems: the fantastic amount of time to prepare good material, the problem of getting the students to use the resources effectively, in particular to keep at the self-paced material. One particularly appealing approach is Pappano's working with the group as part of the team with the evaluation being performed by someone not associated with the course directly.

The sequencing and pacing varies greatly. Tulsa uses 10 of its 17 units on the background laws and equations; McGill uses 7 total units; Clarkson uses 13 units; Arkansas uses 22 units; and Cincinnati uses 15 units. The programs themselves range from the use of texts (such as Wales (1970)), to notes that identify the learning objectives, the rationale, the learning activities and the self-assessment task. MacKenzie et al (1970) suggest that the replacement of one learning environment by another is not ideal; it is better to offer two or more alternative learning environments and let the learner choose. It seems that most have elected to go all self-paced and the two alternatives are not offered. Cornell offers lecture or audio visual. It is interesting that the actual format of how the self-paced programs are run varies from school to school. Some still retain some lectures; some have lectures and tutorials; some have laboratories.

SUMMARY OF CHALLENGES

Three major challenges were voiced repeatedly:

- To provide sufficient drill so that problem-solving, and doing a mass and/or energy balance are second nature. The challenge is to get the students to appreciate the complexity of the problem yet keep each step simple so that they learn it readily. To further complicate matters there is a wide variation in our student's ability with this set of knowledge; perhaps wider than that in other courses. For some students, this is very easy; for others, it is extremely difficult.
- To motivate the students. This is related to the first challenge. However, we need the students to participate sincerely in the discussions, tutorials, in the self-paced programs. The students should be so interested that they are willing to extend themselves. The students want to be turned on. They seek relevancy.
- To develop self confidence maturity and professional attitudes.

Other challenges that can be specific to a particular school include:

- The preparation of new learning environments to better suit the needs of the students and the course objectives.
- The challenge of integrating, selecting and pacing the material: graphical, analytical and computer techniques; problem solving, properties, and conservation concepts; teach as separate course or integrate throughout the program.
- Finding good problems and cases.
- Having enough time available.

IDEAS FOR THE FUTURE

Besides the challenges listed in the preceding section some observations and ideas about the future concern the following topics:

- Unit Systems. There has been a lot of discussion about metrification (see for example Kroner (1972)). Only a few schools seem to have started to include the S1 system. What should we be doing in view of the decision to adopt metric units in the near future?
- Everyone discusses problem solving and developing a problem solving ability. Yet the actual generalized strategy for problem-solving or even the strategy specific to solving mass and energy balances is not described clearly enough. One idea is to use Polya's generalized "four step" stretegy of Define, Plan, Carry out the Plan, Look Back. Within this framework the substeps that offer a unique challenge to a specific type of problem could be discussed. This has been done for design and for plant improvement (see Figs. 4.3 and 4.4 in Crowe et al (1971) p. 76). A start on this for solving mass and energy problems is given in Table 3. Would it be profitable for us to spend more time elucidating the actual strategy for solving problems since this is such a major component of our program?
- Many professors emphasize open-ended problems that require students to locate information for themselves. Some have this as a part of their course now, or as part of other courses in the program. What emphasis should be placed on searching the literature in the Mass and Energy Balance course? Should we define a strategy for searching the literature? A suggested strategy is given in Table 4.
- Engineers need to know something about cost estimation and the financial aspects of an enterprise. Some introduce this as part of the course. Should we introduce more or is it too early in the program?
- We believe it is important to develop a professional attitude. How do we go about "teaching" it? What components of it should the students experience in the Mass and Energy Balance course?
- There is a need to define the criteria used by engineers to make decisions. These include technical feasibility,

TABLE 3: Generalized Strategy for Problem Solving

General	Specific to Mass & Energy Bal.
DEFINE:	
Identify need: accuracy & time available	
Specify criteria: technical, economic, financial, resources, social market ability, environment	
Identify system:	Draw a neat flow diagram. Identify boundaries or envelope. Classify type of operation (reaction-non-reaction; steady-state or transient; recycle?)
Identify system parameters:	Choose a basis, write stoichiometry. Identify unknowns, degrees of freedom. Identify fundamental constraints
Collect information:	Cite source
PLAN:	
Develop models & set up equations	Identify subproblems, clearly state assumptions, Identify tie elements.
Decide on Solution Strategy	Use Method of Successive Approximation or not?
Select Mathematical Technique	
CARRY OUT:	
LOOK BACK: Check reasonableness; Reiterate if necessary; Communicate results	
DISCUSSION: Polya (1945); Thatcher (1962) Chapt 3 p. 57 to 68; Whitwell & Toner (1969) 38 p. 101 to 153; Andersen and Wenzel (1961) p. 174	Henley & Bieber (1959 Chpt. 3 p. 11 to 15; Tyner (1960) p. 3; Himmelblau (1967) p. 33 to 34 & thruout

economic, financial, environmental, socially accepted feasibility. How much of this should be in this course?

• The students should have some appreciation of processing equipment, how it works and what it looks like. Rudd, Powers and Siirola (1972) handle this primarily via a glossary. Myers and Sieder (1972) discuss key equipment needed for the flow diagrams and processes they discuss in their book. Some use plant tours, others use experimental labs. Perhaps it would be worthwhile to discuss the importance and alternative approaches that could be used to discuss this.

• There seem to be relatively few movie films available for this course. Are the ones available useful? Should more be developed?

• Finally, some are interested in learning more about good case studies. Some are using them now, some are described elsewhere (Walker and Delgass (1972)). Should we publish, like the AIChE case problems, a list and evaluation of cases useful for Mass and Energy Balances at the freshman-sophomore level?

SUMMARY

The content, learning environments, and student characteristics reported for a course "Introduction to Mass and Energy Balances" have been reviewed. The content centers around problem-solving and the conservation concepts with an introduction of the appropriate material on units and the properties of matter. The major learning activity is problem-solving as homework with lecturing being the primary learning environment. The students are not used to poorly defined problems or the use of order-of-magnitude calculations. They are searching for relevency, especially in view of the image the chemical industry has concerning pollution and employment.

In general, a lot of exciting innovations are

TABLE 4: Generalized Strategy for Searching the Literature

General	Specific to Searching the Lit.
DEFINE:	
Identify need: accuracy & time available	clear statement of information needed
Specify criteria:	purpose, reader
Identify system:	where information sought fits in information resources available
Identify system parameters:	check in encyclopedias, dictionaries, thesauri for good definitions, for synonyms generate search statement.
PLAN:	
Decide on Solution Strategy:	successive approximation?
Develop search strategy	Identify "most" likely source of information (article, book, patent? person?) Select resources that will help locate soure. Search by subject? by author.
CARRY OUT:	
LOOK BACK: Check reasonableness; Iterate if necessary; Communicate results	
DISCUSSION: Woods, Stone and Black (1969); Woods (1970)	

being tried: innovations in content, in motivation and in learning environment. The interesting trends in content are shifts toward case studies, design, problem solving and mathematics-systems. The challenge in motivating the students is met by careful choice of examples and pacing. The choice of learning environment is extremely important. Many are using self-paced environments. Some points for discussion are enumerated. □

Acknowledgement

This article is a condensation of the original survey. More details can be obtained from D. R. Woods. This survey was made possible by the financial support of the Department of Chemical Engineering, McMaster University, Hamilton, Canada. We appreciate the assistance of Ms. Susan Anderson, Sheelagh Swords Courtney and Charlotte Traplin of that Department for their help in collecting and collating the information.

REFERENCES

Anderson, L.B. and Wenzel, L.A. (1961) "Introduction to Chemical Engineering" McGraw-Hill, New York.

Balzhiser, R., Samuels, and Eliassen, J.D. (1971), "Chemical Engineering Thermodynamics", Prentice-Hall.

Bloom, B., et al (1954) "Taxonomy of Educational Objectives: Cognitive Domain", David McKay, New York.

Blum, J.J., (1971), "Introduction to Analog Computation", Harcourt-Brace, Jovanovich Inc.

Bodman, S.W., (1968) "The Industrial Practice of Chemical Process Engineering" The MIT Press.

Brian, P.T.L. (1972) "Staged Cascades in Chemical Engineering", Prentice-Hall.

Crowe, C.M. et al (1971) "Chemical Plant Simulation", Prentice-Hall.

Denbigh, K.G. (1971) "The Principles of Chemical Equilibrium" 3rd ed. Cambridge, Cambridge.

Dorf, R.C. (1969) "Matrix Algebra: A Programmed Introduction", Wiley.

Henley, E.J. and Bieber, H. (1959) "Chemical Engineering Calculations: Mass and Energy Balances" McGraw-Hill, New York.

Henley, E.J. and Rosen, E.M. (1969) "Material and Energy Balance Computations", Wiley, New York.

Henley, E.J. and Staffin, H.K. (1963) "Stagewise Process Design", Wiley, New York.

Himmelblau, D.M. (1967) "Basic Principles and Calculations in Chemical Engineering". 2nd ed. Prentice-Hall, Englewood Cliffs, New Jersey.

Hougen, O.A., Watson, K.M. and R.A. Ragatz (1954) "Chemical Process Principles. Part I Material and Energy Balances" second edition, Wiley, New York.

King, C. Judson (1971) "Separation Processes", McGraw-Hill and series of case studies in design and simulation, available from Dr. King, Dept. of Chemical Engineering, Univ. of California at Berkeley, Berkeley.

Krathwohl, D., et al (1964). "Taxonomy of Educational Objectives: Affective Domain". David McKay, New York.

Kroner, K.E. (1972). "Metrification—our Responsibility?". Engng. Education 63 1 p. 53.

MacKenzie, Norman, Eraut, Michael and Jones, H.C. (1970). "Teaching and Learning: An introduction to new methods and resources in higher education". UNESCO and the International Association of Universities.

Meissner, H.P. (1971) "Processes and Systems in Industrial Chemistry", Prentice-Hall.

Myers, A.L. and Seider, W.D. (1972) "Chemical Process Logic", Univ. of Pennsylvania, Philadelphia, Penn.

Polya, G. (1945) "How to Solve It", Princeton Univ. Press, Princeton, N.J.

Ranz, W.E. (1970) "Describing Chemical Engineering Systems", McGraw-Hill.

Rudd, D.F., Powers, G.J. and Siirola, J.J. (1972) "Process Synthesis", Prentice-Hall.

Russell, F. and Denn, M. (1972) "Introduction to Chemical Engineering Analysis", Wiley, New York.

Schmidt, A.X. and List, H.L. (1962) "Material and Energy Balances", Prentice-Hall.

Seagrave, R.C. (1971) "Biomedical Applications of Heat and Mass Transfer", The Iowa State Univ. Press, Ames. Journal 50010.

Sherwood, T.K. (1963) "A Course in Process Design", The MIT Press, Cambridge.

Shreve, R.N. (1967) "Chemical Process Industries", 3rd ed. McGraw-Hill.

Smith, Buford D. (1967 ff) Series of case studies in process design—simulation available from Dr. Smith, Dept. of Chemical Engineering, Washington Univ., St. Louis, Missouri.

Smith, J.M. and van Ness, H.C. (1959) "Introduction to Chemical Engineering Thermodynamics", McGraw-Hill.

Sonntag, R.E. and van Wylen, G.M. (1971) "Introduction to Thermodynamics: classic and statistical", Wiley.

Stephenson, R.M. (1966) "Introduction to the Chemical Process Industries", Reinhold.

Thatcher, C.M. (1962) "Fundamentals of Chemical Engineering", C.E. Merrill Books, Columbus, Ohio.

Tyner, Mack (1960) "Process Engineering Calculations", The Ronald Press.

Wales, C.E. (1970) "Programmed Thermodynamics", McGraw-Hill.

Wendland, R.T. (1971) "Petrochemicals—the New World of Synthetics", Doubleday.

Whitwell, J.C. and Toner, R.K. (1969) "Conservation of Mass and Energy", McGraw-Hill.

Williams, E.T. and Johnson, R.C. (1971) "Stoichiometry for Chemical Engineers", McGraw-Hill.

Woods, D.R., Stone, E. and Black, S.M. (1969) "Resources for Searching the Literature with examples in the field of Business-Economics". Chem. Eng. Dept., McMaster Univ., Hamilton, Canada.

Woods, D.R., (1970) "Resources and Mechanics of Searching the Literature with examples for the Chemical Engineer" Chem. Eng. Dept., McMaster Univ., Hamilton, Canada.

Walker, C.A. and Delgass, W.N. (1972) Chem. Eng. Ed. 6 No. 3 p. 124.