A PROJECT-BASED, SPIRAL CURRICULUM FOR INTRODUCTORY COURSES IN CHE

Part 1. Curriculum Design

William M. Clark, David DiBiasio, Anthony G. Dixon
Worcester Polytechnic Institute • Worcester, MA 01609

Engineering education in the United States today faces many challenges, including: 1) attracting students with a diversity of backgrounds, learning styles, and pre-college preparations for engineering careers; 2) maintaining interest and motivation during a four-year undergraduate education, while at the same time assuring quality and relevance to engineering practice; 3) preparing students for demanding careers that not only require technical competence in an engineering discipline but also require communication, teamwork, and life-long learning skills; and 4) maintaining or enhancing quality programs in the face of increasing financial pressure.[1,2] Since the traditional approach to chemical engineering education was designed for a somewhat different set of challenges, we question whether it is well suited to meet today's needs.

***William M. Clark** is Associate Professor of Chemical Engineering at WPI. He holds BS and PhD degrees in chemical engineering from Clemson University and Rice University, respectively, and has 13 years of experience teaching thermodynamics, unit operations, and separation processes. His educational research focuses on developing and evaluating computer-aided learning tools.*

***David DiBiasio** is Associate Professor of Chemical Engineering at WPI. He received his BS, MS, and PhD degres in chemical engineering from Purdue University. His educational work focuses on active and cooperative learning and educational assessment. His other research interests are in biochemical engineering, specifically biological reactor analysis.*

***Anthony G. Dixon** is Professor of Chemical Engineering at WPI. He holds a BSc degree in mathematics and a PhD degree in chemical engineering from the University of Edinburgh. His research has included development of interactive graphics software to aid in teaching process design and mathematics to engineers.*

In the traditional approach, the chemical engineering curriculum provides a compartmentalized sequence of courses that aims to build a solid, fundamental foundation before providing integrated, capstone and/or engineering practice experiences in the senior year. Problems that arise from this educational structure include

- Lack of motivation for learning fundamental material
- Poor retention of sophomore- and junior-level material that is needed for the senior-year integrated experiences
- Segmented learning resulting in a lack of ability to integrate material presented in several different courses
- Lack of ability to extrapolate knowledge and skills gained in one context (*e.g.*, thermodynamics) to a different context (*e.g.*, thermodynamic limitations in reactor design)

While cognitive science indicates that repetition is central to learning,[3] all too often important material is presented once and assumed to be "learned." Moreover, the traditional lecture format has not been conducive to accommodating different learning styles or to a desirable shift away from passive learning to active learning.[4,5]

To address the challenges and deficiencies noted above, we have developed a project-based, spiral curriculum for our chemical engineering sophomore year. The new curriculum is "spiral" because the understanding of basic concepts and their interrelations is reinforced by revisiting them in different contexts with increasing sophistication each time. It is

The new curriculum is "spiral" because the understanding of basic concepts and their interrelations is reinforced by revisiting them in different contexts with increasing sophistication each time

"project-based" because students learn and apply chemical engineering principles by actively completing a series of projects (including open-ended design projects and laboratory experiments) throughout their first year of study, rather than by simply passing a series of tests on related but compartmentalized subjects in a lecture-based course sequence.

In this series of papers we will describe the design, implementation, and evaluation of the new curriculum. This paper presents the philosophy, objectives, and curriculum design. Subsequent papers will describe the details of the projects and curriculum, our implementation experiences, and our extensive assessment efforts. Although some features of the new curriculum are unique to Worcester Polytechnic Institute (WPI), we anticipate that much of it will be transferable to other settings and timetables and that our approach can serve as a model for other engineering disciplines.

TABLE 1
Typical Schedule of WPI ChE Core Courses

	Term A	*Term B*	*Term C*	*Term D*
	(Fall Semester)		*(Spring Semester)*	
Sophomore	Material and Energy Balances	Classical Thermodynamics	Mixture Thermodynamics	Staged Separation Processes
Junior	Fluid Mechanics	Heat Transfer	Mass Transfer	Kinetics and Reactor Design
Senior	Unit Operations Laboratory I	Unit Operations Laboratory II	Process Control Laboratory	Applied Math for Chem. Eng.
	Process Design and Economics	Chemical Plant Design Project		

BACKGROUND

The problems noted above are neither newly discovered nor limited to chemical engineering. There are ongoing efforts aimed at addressing these same problems in engineering programs across the country. These efforts can be placed into three main categories that differ in approach from the one described here. First, there are programs aimed at integrating math, science, English, and engineering subjects at the freshman and sophomore level before beginning discipline-specific studies. Drexel's E^4 program, some of the National-Science-Foundation-supported Engineering Education Coalitions, and several other programs have focused on providing an active learning integrated curriculum that introduces engineering practice to freshman and sophomore students.[6-13] All of these programs focus on interdisciplinary or general engineering principles at the earliest level of engineering education, whereas our new curriculum is directed toward more in-depth study of core chemical engineering courses. The project-based, spiral curriculum could thus follow one of the newly developed interdisciplinary introductory programs, or it could follow a more traditional basic math-and-science introductory curriculum, as is currently the case at WPI.

The second type of related-but-different approach to reform is aimed at bringing the excitement of engineering design to the freshman level as a motivational introduction to engineering without necessarily reorganizing the entire freshman experience. In some cases there are cross-disciplinary "introduction to engineering" courses[14-15] and in others there are discipline-specific introductory courses.[16-17] The third type of reform effort aims to provide design across the curriculum by integrating design into existing courses throughout the curriculum.[18-21]

Virtually all of the recent reform efforts have incorporated proven learning-enhancement strategies of active, cooperative learning,[22,23] and problem-based or project-based learning.[24,25] We have also used these strategies, but what distinguishes our program is that we have completely reformed the first set of core chemical engineering courses to emphasize these features and to integrate material that is normally taught in a compartmentalized sequence of fundamental courses.

OUR TRADITIONAL CURRICULUM

WPI has an atypical academic calendar consisting of five seven-week terms; four during the regular academic year and an optional, fifth one during the summer. Normally students take three courses or activities during each of the four academic-year terms denoted terms A, B, C, and D, and complete their studies in four years. Our A and B terms correspond to Fall semester, and C and D correspond to Spring semester in other programs. The typical sequence of core chemical engineering courses encountered by our students is presented in Table 1. During their freshman year, they study chemistry, physics, calculus, and humanities or social science electives. Their first exposure to chemical engineering begins in their sophomore year. In addition to the core material balance and thermodynamics courses shown in Table 1, they normally take physical chemistry, organic chemistry, differential equations, and more humanities and social science courses in their sophomore year. During their junior year, students usually take engineering electives and complete a three-course-equivalent "interactive qualifying project" relating science and technology to society in addition to completing the transport and reactor design courses shown in the table. During their senior year, all of our students complete a three-course-equivalent "major qualifying project," similar to a senior thesis, in addition to the unit operations, design, and control courses shown.

Although the format is different, the core content of our curriculum is similar to that of most other chemical engineering departments. We teach the fundamental subjects underlying chemical engineering process analysis and design in a compartmentalized sequence of courses during the sophomore and junior years. Then, in the senior year we ask the students to work in teams on integrated laboratory and design problems using those fundamentals. In addition to assigning complex, open-ended problems for the first time, we also emphasize teamwork and oral and written communication skills for the first time in the senior year.

This process has been likened to the following hypothetical method of training a baseball team. Suppose you take nine people who don't know the game of baseball and train them individually in all the fundamentals for two years; two months on throwing, three months on catching, five months on hitting, etc. Then, without ever having them practice, or even watch a game, you suddenly ask them to play the game properly as a team. Many would likely quit after the first few months because they didn't like throwing the ball over and over when they didn't know why they were doing it. Those that survived the program would probably play well at the end, but they'd have bruises from those first few games when they knew the fundamentals but not how to put them together.

Our students often complain that the first half of their senior year was the hardest thing they have ever done, but at the same time acknowledge that it was their best educational experience. They recognize that solving practical laboratory and design problems and communicating their results forced them to relearn and better understand the fundamentals as well as prepared them for the role of a practicing engineer. Part of our motivation for the project-based, spiral curriculum was to bring some of these rich senior-year experiences into the earlier years.

Although we have recently begun incorporating active and cooperative learning exercises within some of our courses, the format of lecture/followed by homework/followed by test, dominated the learning process. Our students use computers for word processing, spreadsheets, math packages, programming, and the process modeling and design program AspenPlus, but there is no emphasis on computer use and no specific computer skills development strategy. AspenPlus is not used until the senior-year design course.

TABLE 2

Goals of the New Curriculum

- Integrate material from our first four core courses
- Reinforce key concepts by repetition with increasing complexity
- Provide semirealistic applications of fundamentals
- Provide laboratory and design experiences
- Emphasize active learning
- Integrate computer use throughout the curriculum
- Introduce AspenPlus to sophomores
- Improve student motivation for learning fundamentals
- Improve problem-solving abilities
- Improve mastery of fundamentals
- Improve communication skills
- Improve teamwork skills
- Maintain individual accountability
- Promote lifelong learning
- Improve attitudes and satisfaction with chemical engineering
- Use computer-aided instruction and peer learning asistants to maintain costs

OUR NEW CURRICULUM

The goals of our new curriculum are listed in Table 2 and can be seen to be consistent with the goals of ABET's Engineering Criteria 2000.[26] These goals should result in students who can work effectively in teams to combine material and energy balances with thermodynamics, transport phenomena, chemical kinetics, and reaction engineering to analyze and design chemical processes.

In considering how best to achieve these goals, we used our baseball analogy and wanted students to play some practice games and enjoy what they were doing as they developed their fundamental skills. We wanted them to encounter some semirealistic chemical process analysis and design problems throughout their chemical engineering studies, rather than only at the end. We hypothesized that a series of well-structured projects could provide motivation for learning fundamentals as well as provide practical applications of those fundamentals. Integrating material throughout the curriculum would reinforce interrelationships between subjects and help develop abilities to solve realistic problems.

To completely fulfill our plans, we realized, however, that the entire first two years of chemical engineering courses would have to be reorganized. Beginning knowledge and skills from several traditional courses needed early introduction to accommodate meaningful, but carefully structured, early projects. Knowledge and skills could then be added on a "just-in-time" basis to help students progress through a series of projects with increasing complexity. There was no need to change our senior year, because it already had integrated, project-based, team-oriented laboratory and design experiences.

Although we realized that integration of all material from the sophomore and junior years was important, we decided to focus only on the sophomore year. We thus sought the more modest goal of integrating material and energy balances with thermodynamics and stage-wise separation processes, hoping to produce rising juniors who could work in teams to combine these subjects to analyze and design processes, albeit those without regard to rate behavior. Reasons for neglecting to integrate the transport and reactor courses into our new curriculum included: 1) complete reform of two year's curriculum seemed unmanageable; 2) meaningful projects could be done that did not require rate information; 3) some of our transport courses are taken by non-chemical engineering students and/or are taught by non-chemical engineering professors; 4) many of our students study off-campus for one or more terms during their junior year, creating scheduling problems with a year-long integrated junior-year course; and 5) senior-year courses provide an opportunity to integrate the rate material with other topics.

Since a major revision of the sophomore year was required, we took the opportunity to introduce other desirable features into the new curriculum. As shown in Table 2, most (but not all) of the goals followed directly from our desire to produce students with the ability to "play the game" and not just those who could "hit well in batting practice." Although not a specific goal of our new sophomore-year curriculum, one additional positive outcome might be that the student's senior year becomes more enjoyable as well as more productive. This might happen because students who go through the new curriculum as sophomores will have experience with team-based integrated projects before their senior year.

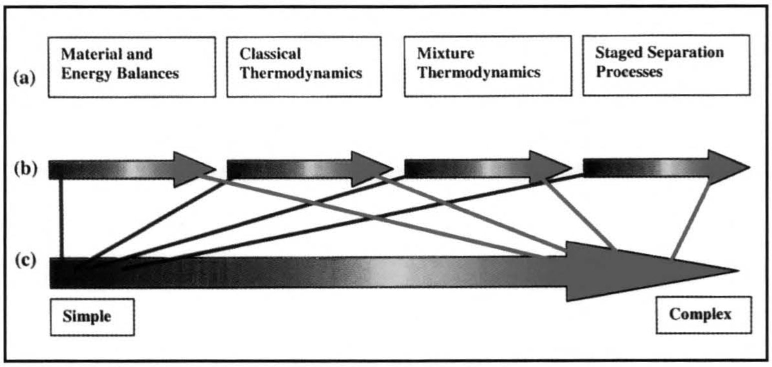

Figure 1. *Rescheduling the traditional curriculum from simple-to-complex. (a) traditional four courses; (b) within each course material flows from simple (blue) to complex (red); (c) a new year-long course with material from each of the four traditional courses rearranged from simple to complex.*

DESIGN OF THE NEW CURRICULUM

To develop our new curriculum, we itemized and prioritized detailed learning objectives for the four traditional sophomore-year courses (see Figure 1a). We noted that in each course the material progressed from simple to complex, as illustrated with the color-coding in Figure 1b. In one sense, what we sought was a year-long course that integrated topics from the four traditional courses by teaching the beginning material from each course in a new first course, followed by the intermediate material from each traditional course in a new second course, and so on, as illustrated in Figure 1c. We also wanted to revisit key concepts throughout the year and to emphasize the connection of ideas normally presented separately in separate courses. We therefore developed the "spiral" curriculum concept, shown schematically in Figure 2. The sophomore year was divided into four levels shown in the vertical direction of the diagram and corresponding to our four terms. At WPI the four levels correspond to discrete courses, but that need not be the case. For example, in a semester system, the material from levels 1 and 2 could be taught in a single 5-6 credit semester-long course.

Our four traditional courses are shown at the base of the diagram to provide a reference frame for com-

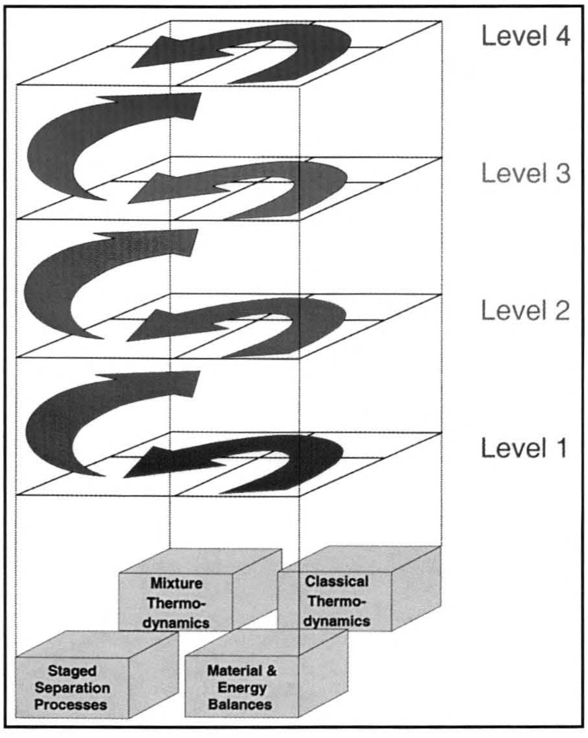

Figure 2. *Schematic diagram of the spiral curriculum.*

parison. Students begin the new curriculum at Level 1, where they are introduced to the basic skills and concepts from all four traditional courses. In Level 2, in addition to introducing new material we build on the previously acquired skills and concepts by requiring them to be re-used and extended to more complex tasks. The succeeding two levels follow similarly, with the students revisiting topics met before at lower levels, extending them to more sophisticated uses and ideas, as well as acquiring new knowledge and concepts needed to address more challenging problems.

Table 3 presents the results of prioritizing and rearranging important topics from our sophomore year into a spiral curriculum with four levels. At Level 1, we introduced simple material and energy balances with no recycle, the thermodynamics of pure components, first-law energy balances, ideal-phase equilibria, and simple flash separations. At Level 2, students were exposed to ideas of recycle, staged separation systems, and the applications of energy balances to flow systems. Non-ideal gas-phase behavior was introduced through entropy concepts in the analysis of flow processes and the use of real gas relations, including residual properties. The students' experience with separation equipment was broadened first by extensive coverage of distillation at the start of the level, followed by a short look at isothermal gas absorption toward the end. In Level 3 the focus was on the properties of mixtures, especially non-ideal solutions

TABLE 3
Curriculum Material by Level

Level	*Topics*
1	***Material balances and stoichiometry***
	• unit conversions, temperature and pressure scales, mass, mole fractions
	• stoichiometry, conversion, yield, limiting and excess reactants
	• density; ideal gas law and partial pressure
	• non-reactive material balances; choice of basis
	• material balances on reactive systems; tie components
	Energy balances—first law
	• properties of pure fluids
	• gas-liquid systems, relative saturation
	• phase rule, vapor pressure, Raoult's law
	• W, Q, U, 1st law for closed systems; reversible systems
	• enthalpy, 1st law for steady-flow processes
	• thermodynamic data: steam tables, ΔH, c_p
	• heat effects for phase changes
	• energy balance applications
	Introduction to staged separations
	• binary VLE, y-x diagram, bubble and dew-point calculations
	• multicomponent VLE; K-factors
	• single-stage binary flash
	• single-stage multicomponent flash
	• multistage distillation and external column balances
	• introduction to McCabe-Thiele methods
2	***McCabe-Thiele methods for binary distillation***
	• stage-to-stage calculations
	• enriching and stripping sections, feed line
	• effect of reflux ratio, plate efficiency
	• introduction to non-CMO methods
	2nd law, thermodynamics of steady flows
	• material balances on reactions, excess air
	• heat effects of industrial reactions
	• entropy, 2nd law of thermodynamics
	• Carnot heat engine, thermal efficiency
	• combined law of thermodynamics, fundamental property relations
	• steady-flow processes, efficiencies of flow devices
	• power cycles
	• thermodynamic analysis, thermodynamic efficiencies
	• refrigeration
	Material balances with recycle; real gases; absorption
	• material balances with recycle, purge, and by-pass
	• real gases and compressibility; cubic equations of state
	• real gas mixtures, Kay's rule
	• critical properties, acentric factor and principles of corresponding states
	• residual properties and compressor, turbine analysis
	• isothermal absorption of gases in staged equipment
	• Kremser equations for dilute gas absorption; plate efficiencies
3	***Property changes on mixing***
	• partial molar properties, ideal solution, and excess properties
	• heat effects of mixing—heats of solution, formation
	• enthalpy-concentration charts; adiabatic mixing
	Solution thermodynamics and VLE
	• phase rule, vapor-liquid equilibrium in ideal mixtures
	• corrections to ideal-solution behavior, activity coefficient models
	• excess Gibbs energy and activity coefficient models
	• chemical potential and equilibrium criterion
	• fugacities and fugacity coefficients
	• activity coefficients and standard states
	• low-pressure VLE calculations
	• solubility of a gas in a liquid; VLE from EOS
	• calculation of fugacity for pure components, mixtures
	• azeotropes and distillation
	Liquid-liquid extraction
	• liquid-liquid equilibria
	• immiscible extraction: LLE, single stage
	• immiscible extraction: multistage methods
	• miscible extraction: LLE, lever rule
	• miscible extraction: single-stage and cross-flow
	• miscible extraction: multistage cross-flow
4	***Chemical reaction equilibria***
	• reaction coordinate
	• standard heat of reaction, standard Gibbs energy of reaction
	• evaluating equilibrium constants
	• relating equilibrium constants to composition
	• equilibrium conversion for single reactions
	• Le Chatelier's principle
	• multireaction equilibria
	Unsteady-state balances
	• transient material and energy balances; filling tanks and cylinders
	• staged batch distillation
	Combined material and energy balances
	• non-CMO distillation, Ponchon-Savarit method
	• psychrometry; psychrometric charts; adiabatic humidification
	• computer-aided material and energy balances; degrees of freedom
	• simultaneous material and energy balances on reactive processes

and phase equilibria. Property changes on mixing were followed by vapor-liquid equilibria and, finally, liquid-liquid equilibria. In the latter two cases, the thermodynamic material was coupled strongly to applications involving distillation of azeotropes and liquid-liquid extraction, respectively. Finally, in Level 4, chemical reaction equilibrium was covered, followed by advanced process calculations, including unsteady material balances and simultaneous material and energy balances. We also provided brief exposure to the process simulator, AspenPlus, in Level 4.

Important topics from lower levels were revisited with more sophistication at higher levels, and each level contained material from each of the four traditional courses. We attempted to distribute the traditional material evenly throughout all four levels, but this was not always possible.

It should be noted that Table 3 indicates the level at which a topic is first introduced. Important topics from lower levels were revisited with more sophistication at higher levels, and each level contained material from each of the four traditional courses. We attempted to distribute the traditional material evenly throughout all four levels, but this was not always possible. Material balances, for example, were introduced early in Level 1 for acyclic systems, including stoichiometry and reactive systems. Material balances on reactions were revisited in Level 2 for heat effects associated with combustion, then were more formally extended to include recycle systems. Little formal instruction on material balances took place at Level 3, but at Level 4 the topics of unsteady material balances and combined material and energy balances, with reaction, were taken up. Topics in staged separations were distributed quite successfully throughout the curriculum, coupling somewhat with the student's increasing sophistication in the use of phase equilibria. Distillation, in particular, appeared in some form in all four levels, moving from simple flash distillation to staged binary distillation to distillation of azeotropic mixtures to unsteady staged-batch columns and non-constant molal overflow operations. The hardest material to fit into the spiral form was solution thermodynamics, since it is conceptually more advanced for most students. Level 1 used Raoult's law for vapor-liquid equilibria, but we did not find it advisable to develop this theme further until Level 3, when the usual topics in VLE were covered. Nevertheless, we found that spiraling of separation processes eased the introduction of solution thermodynamics.

This new curriculum forced repetition of high-priority learning objectives throughout the entire year and emphasized their connection to ideas usually presented entirely separately in a later course. Low-priority learning objectives were de-emphasized and some were omitted, subscribing to the "less is more" philosophy that prefers a clear understanding of key concepts over superficial exposure to almost everything. Thus, by the end of the year every student should realize that chemical engineers are called upon to combine material and energy balances with thermodynamic information to analyze or design processes.

The spiral curriculum was structured around a series of industrially relevant cooperative-group projects that served as a framework for achieving the learning objectives for each level. Within each level in Table 3, topics are grouped together under headings that describe projects designed for each level. In Level 1, for example, the initial project focused on material balances and stoichiometry, the second focused on energy balances, the third introduced staged separation processes. Some projects were design oriented, some were mostly analysis, and others included laboratory experiments. Project deliverables included written reports and sometimes included oral reports. The projects themselves are described in detail in the second paper of this series.

IMPLEMENTATION AND EVALUATION

We taught the spiral curriculum to one-third of the 1997-98 sophomore class and to one-half of the sophomore class in 1998-99. The other sophomores were taught by the traditional curriculum each year and were used as a comparison for assessment of our curriculum reform. The spiral curriculum was delivered through a variety of channels, including cooperative-group projects, traditional lectures, homework problems, in-class active learning sessions, interactive multimedia learning tools, and laboratory experiments. To assure individual accountability, individual homework grades were recorded and an individual test was given at the end of each project period. A thorough understanding of the projects prepared students for most of the material on the tests, but some material was covered only in supplemental lectures and homework problems. Details of our delivery methods and our implementation experiences will be given in Part 2 of this series.

Our overall project assessment goals were to evaluate how the project-based, spiral curriculum affected students' ability to: solve problems at several levels of cognition, work in teams, work independently, master the fundamentals of chemical engineering, and integrate material from several

Continued on page 233.

Project-Based, Spiral Curriculum

Continued from page 227.

courses. We were also interested in how it affects student attitudes and satisfaction about chemical engineering and their professional development within the discipline. External consultants were used to provide objective assessment through a variety of qualitative and quantitative measures. These included surveys, interviews, videotaping of class and project work, end-of-term course evaluations, a novel sophomore process-design competition, and an end-of-year comprehensive exam. The details and results of these assessment efforts will be described in Part 3 of this series of papers.

The following quotes from students on what they like most about the class after our first offering of the new curriculum support our belief that it was well received by students and that at least some of our objectives were met:

> *"...this cooperative learning thing through group projects has made this class one of the most thorough learning experineces of my life. I found it much easier to do assigned homework and do well on tests because of the thought processes established while working on a project."*
>
> *"...the ability to work in groups to solve problems. I really wasn't a big fan of group work because I could usually do just as well on my own. I've come to realize that groups can do so much more than an individual."*
>
> *"...without step-by-step procedures we were really forced to think and comprehend exactly what we were doing and why we were doing it."*
>
> *"...it taught all of us to use our heads first, then use the book. For the first time since coming to college, it felt as if I was learning to do something that would be very valuable to me in the future."*

ACKNOWLEDGMENTS

This project was funded by the U.S. Department of Education's Fund for the Improvement of Postsecondary Education under grant number P116B60511.

REFERENCES

1. Guskin, A.E., "Reducing Student Cost and Enhancing Students Learning: The University Challenge of the 1990s. Part I. Restructuring the Administration," *Change*, (July/August), p. 23 (1994)
2. Parrish, E.A., "A Work in Progress: WPI and the future of Technological Higher Education," *WPI J.,* **3**, Fall (1995)
3. Haile, J.M., "Toward Technical Understanding. Part 3. Advanced Levels," *Chem. Eng. Ed.,* **32**, 30 (1998)
4. NSF Publication, "Report from the Presidential Young Investigator Colloquium on U.S. Engineering, Mathematics, and Science Education for the Year 2010 and Beyond," (1991)
5. Felder, R.M., and L.K. Silverman, "Learning and Teaching Styles in Engineering Education," *J. Eng. Ed.,* **78**, 674 (1988)
6. Quinn, R.G., "Drexel's E^4 Program: A Different Professional Experience for Engineering Students and Faculty," *J. Eng. Ed.,* **82**, 196 (1993)
7. Parker, J., *et. al.,* "Curriculum Integration in the Freshman Year at the University of Alabama: Foundation Coalition Program," paper 4a11, *Proc. 25th Frontiers in Ed. Conf.,* Atlanta, November (1995)
8. Richards, D.E., "Developing a Sophomore Engineering Curriculum: The Rose-Hulman Experience," paper 2b61, *Proc. 25th Frontiers in Ed. Conf.,* Atlanta, November (1995)
9. Coleman, R.J., "Studio for Engineering Practice, 'STEP', Lessons Learned About Engineering Practice," paper 2c42, *Proc. 25th Frontiers in Ed. Conf.,* Atlanta, November (1995)
10. Felder, R., L. Bernhold, E. Burniston, J. Gastineau, and J. O'Neal, "An Integrated First-Year Engineering Curriculum at North Carolina State University," paper 4d42, *Proc. 25th Frontiers in Ed. Conf.,* Atlanta, November (1995)
11. Froyd, J.E., "Integrated, First-Year Curriculum in Science, Engineering, and Mathematics: A Ten-Year Process," paper 4d44, *Proc. 25th Frontiers in Ed. Conf.,* Atlanta, November (1995)
12. Miller, R.L., and B.M. Olds, "Connections: Integrated First Year Engineering Education at the Colorado School of Mines," paper 4a12, *Proc. 25th Frontiers in Ed. Conf.,* Atlanta, November (1995)
13. Panitz, B., "The Integrated Curriculum," *ASEE Prism,* **7**(1), 24 (1997)
14. Richards, L.G., and S. Carlson-Skalak, "Faculty Reactions to Teaching Engineering Design to First Year Students," *J. Eng. Ed.,* **86**, 233 (1997)
15. Yokomoto, C.F., *et al.,* "Developing a Motivational Freshman Course Using the Principle of Attached Learning," *J. Eng. Ed.,* **88**, 99 (1999)
16. McConica, C.M., "Freshman Design Course for Chemical Engineers," paper 174c, 1998 Annual AIChE Meeting, Miami, FL, November (1998)
17. Solen, K.A., and J.N. Harb, "An Introductory ChE Course for First-Year Students," *Chem. Eng. Ed.,* **32**(1), 52 (1998)
18. Mitchell, B.S., "Early Introduction of Design Fundamentals into the Chemical Engineering Curriculum," *Proc. 1997 Ann. ASEE Conf.,* Milwaukee, WI, June (1997)
19. Woods, D.R., "Introducing Design/Synthesis in Thermodynamics and Transport Courses," paper 236e, Annual AIChE Meeting, Miami Beach, FL, November (1995)
20. Gatehouse, R.J., J.R. McWhirter, and G.I. Selembo, "The Vertical Integration of Design in Chemical Engineering," paper 174e, 1998 Annual AIChE Meeting, Miami, Fl, November (1998)
21. Bauer, L.G., D.J. Dixon, and J.A. Puszynski, "Introduction of Design and AspenPlus across Chemical Engineering Curriculum," paper 174d, 1998 Annual AIChE Meeting, Miami, FL, November (1998)
22. Johnson, D.W., R.T. Johnson, and K.A. Smith, "Maximizing Instruction Through Cooperative Learning," *ASEE Prism,* **7**(6), 20 (1998)
23. Johnson, D.W., R.T. Johnson, and K.A. Smith, *Active Learning: Cooperation in the College Classroom,* Interaction Book Company, Edina, MN (1991)
24. ASEE Prism, "Let Problems Drive the Learning in Your Classroom," *ASEE Prism,* **6**(2), 30 (1996)
25. Woods, D.R., *Problem-Based Learning: How to Gain the Most in PBL,* Waterdown, Ontario, Canada (1994)
26. *Criteria for Accrediting Engineering Programs,* Accreditation Board for Engineering and Technology, Inc., Baltimore, MD (1999) ❐