

A PROJECT-BASED SPIRAL CURRICULUM FOR INTRODUCTORY COURSES IN ChE

Part 3. Evaluation

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This series reports on the development, delivery, and assessment of a project-based spiral curriculum for the first sequence of courses in chemical engineering. The program represents significant restructuring of the introductory chemical engineering curriculum. Traditionally, a compartmentalized course sequence designed to build a conceptual foundation is taught during the sophomore and junior years, followed later by more integrated projects. Our new curriculum requires students to learn and apply chemical engineering principles by completing a series of open-ended design projects starting during their sophomore year. The new curriculum is spiral in that students' understanding of basic concepts is reinforced by revisiting them in different contexts with ever-increasing sophistication.

A more detailed explanation of the concepts, curriculum design, and implementation behind this effort was described in the first two part of this series.^[1,2] Part 1 described the curriculum design, and Part 2 detailed the implementation. In this paper we present the details of the assessment design, describe the results of our assessment, and draw conclusions about the success of the new curriculum.

BACKGROUND

The background describing the need for the new curriculum, the published research upon which it was based, and the philosophy behind our approach was presented in the first paper of this series.^[1] In this section we summarize the literature upon which our assessment plan was based.

An extensive array of literature exists regarding assessment of student learning. An excellent bibliography is available from the Department of Education^[3] and two good resources are available from the National Science Founda-

tion.^[4,5] There are also a number of references that outline the details of assessment plans aimed at continuous improvement.^[6-9] Most of the philosophy and techniques described in those articles are adaptable to individual educational research and curriculum reform efforts.

Assessment tools are generally categorized according to the types of methods and when they are applied during an educational project. There are two broad classes describing the timing of assessment. *Formative assessment* refers to periodic data collection and evaluation prior to project completion. It is used to improve the intervention during the project and helps answer the question, "Is it working?" *Summative assessment* concerns data collection and evaluation at project completion. It is used to make conclusions about project retention, alteration, or elimination and normally answers the question, "Did it work?"

There are two general classes of assessment types. Quanti-

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tative methods are those familiar to most engineers. They include exams (standardized, course exams, comprehensive, oral); surveys with statistical analysis (particularly pre/post); database analysis; written reports (laboratory, design, or research project); graded oral presentations; and graded portfolios. These methods are generally performance-based and measure what students can actually do. Within a discipline-specific context, it is relatively easy to evaluate student performance, but the design of the tool itself may be problematic. These methods can be used to evaluate both team and individual performance. Performance-based tools (authentic evaluation) were pioneered at Alverno College.^[10] O'Conner^[11] described a design-competition approach to performance assessment, and Miller, *et al.*,^[12] present a comprehensive assessment plan involving multiple types of evaluations.

Qualitative methods typically involve analysis of text and visual information. They include videotaping, audiotaping, direct observation, portfolios, self-reports, open-ended surveys, interviews, focus groups, performances, and journals. Engineers have been somewhat slow, however, in finding productive ways to adopt these methodologies that are used in developmental psychology and cognitive science. Most of the methods involve qualitative analysis that is unfamiliar to technologists. The main advantage of methods such as videotaping is that they record actual work—not student interpretations of what was asked of them in a survey. By observing students doing chemical engineering, we can probe how and why they learn. This can yield rich information about the learning process. Sometimes this information is quantified, but usually the results are qualitative.

Marcus^[13] summarized the main features of good and poor assessment plans. The keys to a good assessment plan are: use of both control groups and target groups to minimize variation, including control for contaminating elements; multiple measurements using multiple tools; a mix of formative, summative, quantitative, and qualitative tools; and use of an external evaluator. Good plans define measurable objectives and design the assessment methods directly from those objectives. They implement continuous feedback for improvement, use pre- and post-measurements, and include longitudinal studies when possible. The evaluation plan should uncover program flaws as well as attributes.

Poor assessment plans overemphasize one set of outcomes (for example, affective rather than cognitive) or one type of measurement (all quantitative); vaguely define the performance criteria; do not link data collection to the program;

rely on traditional tests for nontraditional interventions; and develop in-house instruments when validated ones are available.^[13]

Because any single assessment method has advantages and disadvantages, triangulation (the use of multiple measurements) is a key to valid assessment. Evaluation events that occur during and after the intervention are also important. When multiple measurements taken at different time points converge on common results, one can confidently draw conclusions about the observed process or outcomes.

METHODS

Our assessment plan was designed to probe student learning in basic chemical engineering and students' ability to demonstrate learning in both team and individual contexts. We also examined attitudes, satisfaction, and confidence about chemical engineering. For longitudinal data, we looked at individual student performance in follow-on courses in the junior and senior years. Our overall plan combined formative and summative measures and employed both qualitative (interviews, open-ended questionnaires, videotaping of student group work) and quantitative (pre/post surveys, standard course evaluation surveys, individual exams, and team problem-solving competitions) tools. External consultants were used extensively throughout the project.

Intervention and Comparison Cohorts

At the beginning of each implementation year we randomly selected a cohort of incoming sophomores to participate in the spiral curriculum. During the first implementation year, this was about one-third of the class. In the second implementation year, half of the incoming class was randomly selected. Selecting half in the second year meant we eliminated class size as a variable in our analysis. Students not selected were taught in the traditional fashion in a separate section and represented our comparison cohort. Each year we made minor adjustments (prior to the start of the academic year) to insure demographic similarity between the intervention and comparison groups. We also examined grades of each cohort in their first year at WPI. There were no significant differences in first-year performance between the two cohorts.

Since participation in the spiral curriculum was voluntary, students could withdraw at any time during the academic year and move into the comparison section. Only one student did that during the two years of implementation. No students were allowed to self-select into the experimental section. In the following discussion we will refer to the

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intervention group as the *spiral-taught* cohort and the traditionally taught students (the control group) as the *comparison* cohort. Spiral-taught thus refers to all the components of the new curriculum, not simply just the spiral topic structure.

We did our best to control contaminating variables. Both cohorts were taught essentially the same material, using the same textbooks. Both cohorts met for the same number of class periods each week and, as schedules allowed, during the same class hour each day. When scheduling did not allow the latter, we avoided vastly different meeting times. For example, if the comparison group was scheduled at 11:00 a.m., we scheduled the spiral-taught section for close to that hour and avoided times such as 8:00 a.m. or 4:30 p.m.

Problem-Solving Competitions: Team and Individual

Team • At the end of each implementation year, we held a team-based problem-solving competition. All sophomores were invited to participate. Spiral-taught students were placed in teams and comparison students were placed in separate teams. Most students were teamed with others with whom they had not previously worked. We constructed teams with a mix of abilities (judged by grade records) and gender. All participants were paid, and the winning teams from each cohort were awarded additional prize money. This structure meant that from the student standpoint, they were competing only with peers (not comparison groups versus spiral groups). The participation rate was 75% for the first year and 90% in the second year.

Teams were given an open-ended chemical-process problem to solve and had two hours to develop their solution. The problem involved a simple reaction/separation process for the production of formaldehyde from the decomposition of methanol. Students were given the reaction and the desired production rate. They had to develop the process flowsheet, make reactor and material-balance calculations, and choose and design a separation scheme.

Each team selected one group member to present its solution. These ten-minute presentations were videotaped. The presentation videotapes and written student work were sent to three external experts in chemical engineering. Judges were given the problem solution, some guidelines for rating student work, and a form for reporting their analysis of each team's solution. The judges ranked all teams from best-to-worst on the basis of the technical work, not on the presentation quality. The highest ranked spiral team and the highest ranked comparison team were each awarded prize money. We were interested in the comparative rankings of spiral versus comparison teams. Judges were volunteers from academia and industry and had no knowledge of whether the teams were spiral-taught or comparison teams. We also videotaped each team during its two-hour working sessions to help us understand something about the process of solving chemical engineering problems.

Individual • At the end of the second implementation year we held an individual exam competition. Students were given an exam that tested four basic areas of chemical engineering. The exam was open-book and was designed at about Bloom levels 3-4: application and analysis. Again, all sophomores were invited and paid to participate. The participation rate was 61% of the total sophomore class. We offered the exam to juniors to probe long-term retention of basic knowledge. Only four participated, however, yielding too small a sample to draw conclusions. We blind-graded each individual exam using a numbering system that preserved student anonymity. To promote conscientious participation, we offered more cash to students scoring above 70% on the exam.

Questionnaires, Surveys, Interviews

We contracted developmental psychologists from the Frances L. Hiatt School of Psychology at Clark University for our external consultants. Kevin O'Connor and Lisa Comparini were the consultants, with Comparini being with us for most of the project. All questionnaires and surveys were designed by the consultants, and all interviews (in person or electronic) were conducted by Comparini. Both O'Connor and Comparini were intimately involved in the design of the competitions described above. Comparini conducted the analysis of the questionnaires and surveys.

RESULTS

The results from the major assessment measures are summarized below. In all cases, the results were positive regarding the success of the spiral curriculum project. Assessment design allowed us to probe program effects from a variety of different views. The converging results clearly demonstrate the superior educational benefits the new curriculum provided.

Team Problem-Solving Competition

Spiral-taught student teams were judged significantly higher than comparison teams in both years of the team competition.

In the first year, all three judges ranked the spiral teams as the top three of the six participating teams by a wide margin. In the second year, spiral-taught teams were unanimously ranked as the top two of eight total, and four of the top five teams were spiral-taught groups. This clearly demonstrates the ability of spiral-taught students to perform at higher levels than comparison students on open-ended problems.

In general, the judges' comments indicated that spiral-taught teams demonstrated better overall problem analysis than comparison teams. A more global, systems-oriented approach was taken by higher-ranked teams. Spiral-taught teams also showed more progress in generating a flowsheet, completing material balances, and handling equilibrium conversion calculations. Poorer team solutions (primarily comparison groups) were characterized by incomplete flowsheets,

trouble handling reaction products, and an inability to completely couple the reaction and separation portions of the process. Very often, comparison teams focused too much on one particular aspect and failed to demonstrate knowledge of the “big picture.”

This performance assessment was a major milestone in our evaluation. Since one of our objectives was to improve students’ abilities to solve open-ended problems in team situations, the results were very encouraging. Our evaluation plan was not designed to probe individual effects. For example, we did not run a section that had topic spiraling and no cooperative learning. We strongly believe, however, that repeated exposure to spiraled topics (a critical mechanism in improving knowledge retention) coupled with substantive team work is a major reason for the results.

Individual Exam Competition

Spiral-taught students performed better, as individuals, on basic chemical engineering problems.

We were not able to conduct this competition in the first implementation year, but we did conduct it at the end of the second implementation year. Twenty students participated, ten from each cohort. The results are summarized in Table 1 and Figure 1. As a group, the spiral-taught students showed better understanding of chemical engineering. The average score was higher for spiral-taught students and more of them scored above the 50% and 70% levels.

Figure 1 shows that spiral-taught students performed the same or better than comparison students in three of the four areas tested. Those four areas were material balances, classical thermodynamics, staged equilibrium separations, and so-

lution thermodynamics. A clear difference in learning material balances was shown. Spiral-taught students were continuously using this material in different contexts throughout the sophomore year. A similar difference, though not as dramatic, was seen for classical thermodynamics. It is significant that for the case of staged separations, the spiral-taught students had been exposed to the specific material tested (basic McCabe-Thiele calculations) several months prior to the exam. The comparison students were enrolled in the traditional course concerning this material at the time of the exam. Spiral-taught students did not do as well on the solution thermodynamics problem. This area was the most difficult to build into the spiral curriculum and we recognize that it is one area of the curriculum needing improvement.

A typical criticism of cooperative learning is that some students will be carried by their group. The individual exam results and the longitudinal data shown below serve to disprove that notion in our case. Again, the combination of topic spiraling, repeated exposure to open-ended problems, and extensive group work was successful in improving individual student learning.

Longitudinal Effects

Spiral-taught students received higher grades than comparison students in follow-on junior- and senior-level chemical engineering courses.

We tracked students throughout their academic programs to understand how participation in the new curriculum correlated with later performance. Examination of grades in our unit operations laboratory showed that teams comprised of two or more spiral-taught students generally received higher report and oral presentation grades than teams comprised

Cohort	Average Score	# Scores >50%	# Scores >70%
Spiral-Taught	21.7	5	3
Comparison	18.8	3	2

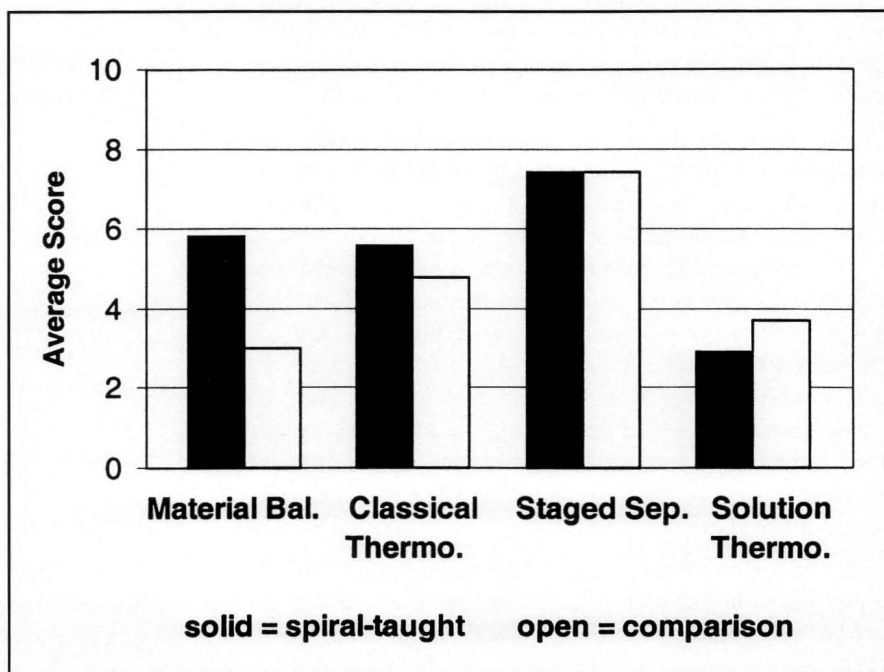


Figure 1.
Average score of each cohort on individual problems. Maximum score per problem was 10 points.

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WPI's upper-level program is heavily project-based. It makes sense that students experienced in project-based learning would show higher levels of performance in similar academic activities as they became juniors and seniors. These projects are similar to senior-level research (BS thesis) projects done at other schools. The first cohort of spiral-taught students graduated this year. Contaminating factors such as mixing of students among spiral-taught and comparison cohorts and upper-level project grade inflation (80% of these projects receive A's) made this analysis uninformative. Of the nine graduating seniors who received awards for outstanding project work, however, five were from the spiral-taught curriculum. For that class, only a third of the graduates were in the spiral-taught cohort.

An alternative to probing project performance is to compare grades of comparison and spiral-taught students in upper-level courses. These courses represent the core knowledge of the discipline and include: fluid, heat, and mass transport; kinetics and reactor design; two process design courses; and two unit operations lab courses. A variety of faculty members, course formats, and teaching methods are used in this mix: large lecture, group work, laboratories, and team-based capstone design. WPI awards only four letter grades (A, B, C, and NR)—there is no D grade. The NR (No Record) grade, typically covers the traditional D-F range and is a "faiure" grade that results in no course credit.

In all cases, spiral-taught students received a higher percentage of A's and a lower percentage of C's than comparison students. For the class of 2000, spiral-taught students represented 33% of the class, yet they accounted for 40% of the A's and only 22% of the C's, from a total of eight core junior- and senior-level courses. For the class of 2001, spiral-taught students represented 50% of the class and accounted for 64% of the A's and only 29% of the C's, from a total of five core junior- and senior-level courses. For both cohorts over two years of data, a total of 35 failing grades were earned in all courses examined. Only three of those were from spiral-taught students, and the same student earned all of them.

This data demonstrates the ability of spiral-taught students to perform at higher levels despite different course formats and variable teaching styles and standards in their upper-level courses.

Attitudes About the Curriculum, the Discipline, and the Faculty

Spiral-taught students showed more positive attitudes about chemical engineering and higher confidence in the major than comparison students.

Student course evaluations are required for all WPI courses. A standard form is used that primarily examines student satisfaction with the instructor. We examined the aggregate responses from all sophomore-level chemical engineering courses for sections taught by all instructors. There were no significant differences between spiral instructors and other faculty. In fact, the percent of positive student responses for the spiral curriculum instructors, as a group, was equal to or higher than that for instructors in the traditional sections (*i.e.*, those teaching the comparison cohort).

When the project started, we planned to implement pre/post surveys during each year. During the first implementation year we observed that results from these surveys gave little information, particularly for the time invested administering them to each cohort. We also made a philosophical decision that surveys with closed wording, forced-choice responses, and fixed topics were not appropriate for our project. We felt this type of evaluation tool, which restricts students responses to predetermined questions, did not allow us to probe a range of possible topics and responses from the students' perspectives. Hence, we used open-ended questionnaires for the remainder of the project.

All sophomores were given a questionnaire at the end of each implementation year. Students were asked about their

TABLE 2
Results from End-of-Year Questionnaire
[Number of students responding each year is in ()]

	<i>Spiral-Taught</i>		<i>Comparison</i>	
	<i>97-98</i> <i>(n=14)</i>	<i>98-99</i> <i>(n=15)</i>	<i>97-98</i> <i>(n=18)</i>	<i>98-99</i> <i>(n=11)</i>
Positive comments	45	61	20	27
Number of topics	19	19	9	15
Negative comments	22	38	22	33
Number of topics	12	14	14	16
<i>Confidence in choice of major</i>				
Positive change	12	12	2	10
Negative change	0	1	5	1
No change	0	2	6	0

expectations for the year and whether or not they were met. They were asked about their choice of major and their confidence in pursuing chemical engineering. We asked what were the 2 to 3 most-valuable and the 2 to 3 least-valuable aspects of their sophomore-year classes. Additional questions included estimates of work effort, quality of teaching assistants, and any general comments. A summary of the content analysis of the results is shown in Table 2. We should keep in mind that these responses were taken from a fairly open-ended questionnaire. The numbers in a particular category do not necessarily represent responses to the same questions. They represent relatively spontaneous numbers of mentioned topics, rather than responses to forced-choice questions.

The overall results show that spiral-taught students were more satisfied with their academic experience and more confident with their choice of major than their peers in the comparison section were. There were about twice as many positive comments made by spiral-taught students on a broader number of topics than by comparison students. The positive comments included topics such as group work, lab work, interaction with the professors, and the projects. Many of the negative comments made by spiral-taught students were about problems that they reported improved during the year (such as "kinks" in early course organization and changing professors) and were generally not about the quality of their overall learning experience.

Negative student comments were particularly revealing. Spiral-taught students complained most about their high workload and about the teaching assistants. The comparison students' complaints were often stated in terms of a deficit (not enough application, not enough material covered, not enough group work, not enough projects, not enough individual attention, not being in the spiral class) and were more suggestive of a dissatisfaction with their overall experience.

Retention in CM

Spiral-taught students showed higher retention rates in the major than did comparison students.

Retention is a key issue when new curricula are implemented. We are probably similar to most departments in that the biggest loss of students from the major occurs during the sophomore year. Historically, our retention rate is about 80%, meaning that 20% of the students enrolling in the first chemical engineering course leave the major by the end of their sophomore year.

We found retention was higher during the sophomore year for spiral-taught students compared to the comparison cohort. Table 3 shows the retention data. Note that in 98-99,

retention in the traditional courses was significantly lower than normal while spiral student retention was maintained at 80%. We interviewed many of the students who left the spiral curriculum and found that reasons were typically related to leaving engineering for one of the sciences (chemistry, biochemistry). An interesting anecdote is that one student who left late in the year said she remained in the spiral curriculum so long only because she liked it so much—eventually it became clear that chemical engineering was not her preferred discipline and she switched to civil engineering.

The Process of Learning Chemical Engineering

We are currently involved in a detailed analysis of the problem-solving session videotapes taken during the team competition. These are the two-hour tapes of each team that were not used for judging team solutions. The tapes have all been transcribed and are being analyzed using techniques similar to Linde, *et al.*,^[14] to study the problem-solving process in spiral-taught and comparison teams. Our methodology for this analysis combines the expertise of a developmental psychologist with that of a chemical engineer.^[15]

Preliminary results indicate that the spiral-taught teams exhibited significantly different teamwork skills than did the comparison teams. Since spiral-taught teams presented better solutions, we are interested in characterizing their process and connecting it to our curriculum design.

We observed that spiral-taught teams behaved more like *practicing* chemical engineers attacking a problem, while comparison teams behaved like *students* of chemical engineering. We've observed significant differences in the use of tools of the profession (authority figures, textbooks, published data, etc.) that points to a model of teamwork somewhat different than the traditional engineering model. None of the teams (comparison or spiral) exhibited any evidence of team dysfunction due to typical problems such as dominant individuals (either intellectually or personality-based), gender bias, lack of participation, or lack of motivation. Successful teams, as rated by external judges, had a greater ability to construct a framework for solving the problem. Unsuccessful teams struggled to do so, and such teams were unable to move toward a framework even when individual members seemed capable of starting the process. We are currently articulating the theoretical basis for these observations and formulating an in-depth description of the model and its relation to the new curriculum.

Areas Needing Improvement

Despite the success of the curriculum as described above, we are aware of three areas where improvement is needed. We attempted to incorporate writing into the curriculum to

TABLE 3
Retention Data for
Sophomore ChE Students

<u>Academic Year and Section</u>	<u>Percent Retained</u>	<u>Total Students at Year End</u>
96-97		
No separate sections	80	62
97-98		
Comparison	80	32
Spiral-taught	88	14
98-99		
Comparison	68	17
Spiral-taught	80	16

exploit the writing-to-learn philosophy. But our efforts lacked consistency, and due to time taken to deliver the new curriculum, we could not implement all we had envisioned. Although spiral-taught students had multiple writing opportunities, a concerted program to improve writing was not possible. Some anecdotal evidence from upper-level writing samples supports the notion that we did have some positive impact on spiral-taught students' writing abilities.

We struggled with spiraling the concepts associated with solution thermodynamics. This is some of the most difficult material that sophomores encounter. In fact, many schools do not teach it until the junior year. The optimal time and location in the curriculum for introducing some of these theoretical concepts is not known. We made improvements from the first to the second implementation year, but our sense is that more work is needed to sort out how students may best understand these concepts.

The final project, for both implementation years, was a significantly different and more complex project than any of those earlier in the year. We asked students to design a project that could be used in future course offerings. The technical material involved some topics of chemical engineering (transient material and energy balances) that are not normally a part of the sophomore year. We believe that students showed mastery of the technical material, but they could not translate that knowledge sufficiently into the context of the project. Hence they developed mediocre-to-poor projects regardless of the team. There appears to be a general intellectual limit to their ability to integrate concepts from earlier in the year and extrapolate them to new situations. We are currently examining that limit by analyzing our evaluation data from those projects.

SUMMARY

We believe our assessment results clearly show the benefits of all the educational activities implemented in the spiral curriculum. In fact, we were quite surprised that differences between spiral-taught and comparison cohorts were so dramatic in so many different areas. Results from a variety of measurements and analysis converged upon a consistent answer.

Compared to traditionally taught students, spiral-taught students displayed equal or better understanding of basic chemical engineering principles, were better in teams at solving open-ended problems, had higher satisfaction levels with their academic experience, had higher retention rates, performed better in upper-level courses, and were more confident about their choice of chemical engineering as a major. Although our evaluation plan could not delineate effects of individual curricular improvements, we believe that frequent open-ended project experiences built around a spiral topic structure were the major reasons for project success.

After extensive discussions, the WPI chemical engineering department voted to permanently adopt the curriculum described in this series of three papers for all our sophomore students beginning in the fall of 2001.

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REFERENCES

1. Clark, W.M., D. DiBiasio, and A.G. Dixon, "A Project-Based, Spiral Curriculum for Introductory Courses in Chemical Engineering: 1. Curriculum Design," *Chem. Eng. Ed.*, **34**(3), 222 (2000)
2. Dixon, A.G., W.M. Clark, and D. DiBiasio, "A Project-Based, Spiral Curriculum for Introductory Courses in Chemical Engineering: 2. Implementation," *Chem. Eng. Ed.*, **34**(4), 296 (2000)
3. Marcus, D., "Notes on Evaluation Design," Fund for the Improvement of Postsecondary Education, Department of Education, web site, accessed August, 1996, at <http://www.ed.gov/offices/OPE/FIPSE/biblio.html> updated January 9, (1998)
4. Frechtling, J., editor, *User-Friendly Handbook for Project Evaluation*, National Science Foundation, NSF 93-152 (1996)
5. Frechtling, J., L.S. Westat, eds., *User-Friendly Handbook for Mixed Method Evaluations*, National Science Foundation, NSF 97-153 (1997)
6. Olds, B.M., and R.L. Miller, "A Measure of Success," *ASEE Prism*, p. 24., December (1997)
7. Rogers, G., "EC2000 and Measurement: How Much Precision is Enough?" *J. Eng. Ed.*, **89**(2), 161 (2000)
8. DiBiasio, D., "Outcomes Assessment: An Unstable Process?" *Chem. Eng. Ed.*, **33**(2), 116 (1999)
9. Rogers, G., "Outcomes Assessment: Opportunity on the Wings of Danger," *Chem. Eng. Ed.*, **33**(2), 106 (1999)
10. Mentkowski, M., and G. Loacker, "Assessing and Validating the Outcomes of College," in *Assessing Educational Outcomes: New Directions for Institutional Research*, Jossey-Bass (1985)
11. O'Connor, K., "Overcoming Obstacles to Boundary Crossing in Multi-Institution Product Realization Projects," proceedings of the Technology Reinvestment Project Grantees Conference, NSF (1997)
12. Miller, J., D. DiBiasio, J. Minasian, and J. Catterall, "More Students Learning, Less Faculty Work?—The WPI Davis Experiment in Educational Quality and Productivity," in *Student Assisted Teaching and Learning: Strategies, Models, and Outcomes*, M. Miller, J. Groccia, and J. Miller, Anker Publishing (2001)
13. Marcus, D., "Evaluation for Second and Third Year and Beyond," Annual FIPSE Project Director's Meeting, Washington, D.C., October (1997)
14. Linde, C., J. Roschelle, and R. Stevens, "Innovative Assessment for Innovative Engineering Education: Video-Based Interaction Analysis," Report to the NSF Synthesis Coalition, Institute for Research on Learning, Palo Alto, CA (1994)
15. Clark, W., L. Comparini, D. DiBiasio, and A. Dixon, "The Process of Learning Chemical Engineering: What Works and What Doesn't," ASEE meeting, St. Louis, MO, June (2000) □