Comprehensive Testing And Outcomes Assessment In The Chemical Engineering Program

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Abstract - **A variety of assessment tools are being used to determine how well graduates from the chemical engineering program are meeting the established outcomes. These tools include student, faculty, employer and alumni surveys, as well as placement data, results of standardized tests, and performance in contests and research presentations. In order to further enhance the objective nature of the outcomes assessment process, an industrial board of advisors has been established to help with the development of additional tools. Members consist of alumni, research collaborators and representatives from a broad spectrum of industry. One of the new tools that have been developed is a 24-hour comprehensive test given as part of the capstone process design class. Problems and suggested solutions are provided by the advisors and tend to be open-ended, covering most of the program outcomes. The response of the students has been favorable and valuable data has been obtained and incorporated into the assessment process. Specifically, the importance of open-ended questions and case studies has become more apparent. Program details and initial results of the comprehensive testing process are presented in this paper.**

Index Terms – Chemical Engineering, outcomes, assessment, comprehensive testing

INTRODUCTION

The approach to education in the Department of Chemical Engineering to education is a holistic one. Via methodologies in place and those being developed, the undergraduate experience can be somewhat tailored to the needs of the specific student. The target is a smooth transition by students into graduate school, industry, or government work upon graduation. The vision and mission of the chemical engineering program are as follows:

Chemical Engineering Program - Vision

Comprehensive education producing high quality chemical engineers

Chemical Engineering Program - Mission

The mission of the chemical engineering program is to provide a personalized environment in which students receive a broad education in the basics of chemical engineering.

Some of the important features of this holistic approach are listed below (also cross-referenced with program objectives and outcomes in Appendix 1):

1. Chemical Engineering Advisory Group
2. Active Internet site for curricular and career matters
3. Industrial mentors, work-study arrangements, independent study
4. Cooperative education and internship opportunities
5. Partnership programs with other universities
6. Opportunity for undergraduate research
7. Opportunity to give back to the community at large: summer camp, girls camp, science fairs, Widener days, Waffles at Widener, CHEER program, etc.[1]
8. Opportunity for technical presentations, publications, contests, technical society activities, independently or co-authoring with faculty (ACS, AIChE, ALCA, NCUR, ISPE, AWMA, International Solid Waste Conferences, etc. [1])
9. Contests and competitive scholarships (local AIChE, National Engineers Week, WERC, AIChE National Paper Contests, etc. [1])

This approach to chemical engineering education has been documented in several pedagogical papers and via joint scientific papers with undergraduate students. [2], [3], [4], [5]

PROGRAM OBJECTIVES

The Chemical Engineering Department has established, with input from our various constituencies (Table 1), a set of program educational objectives that represent the driving force of our chemical engineering program. The objectives are periodically evaluated through formal and informal processes that allow input from the constituencies and provide output to the establishment of expected outcomes.

The program educational objectives are defined to be broad statements describing how the program satisfies the needs of the constituencies and how the mission is fulfilled. The educational objectives provide the motivation for our curriculum and processes via the desired outcomes, consistent with the vision and mission of the School of Engineering and the University. These objectives are presented in Table 2.

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TABLE 1
PROGRAM CONSTITUENCIES

a) Undergraduate Chemical Engineering Students
b) Chemical Engineering Alumni
c) Extramural Groups
   Employers- Cooperative Education, Internship, Permanent
   Advisors - Board of Advisors, ChE Advisory Group, Research Collaborators
d) Chemical Engineering Faculty

TABLE 2
PROGRAM EDUCATIONAL OBJECTIVES

[A] To provide students with a broad base of knowledge in the fundamentals of chemical engineering
[B] To help students develop a desire for life-long learning and professional development
[C] To produce engineers with the ability to excel, in an honorable fashion, in industry, government or academia

The first complete 3-year cycle ended in 2002. Closing the objectives loop (Figure 1) is by its nature a slow process. The faculty meet at the beginning of the next cycle to discuss and review the program objectives. Minor mid-course corrections are made on an annual basis. The process of review and renewal of the objectives is illustrated in Figure 1.

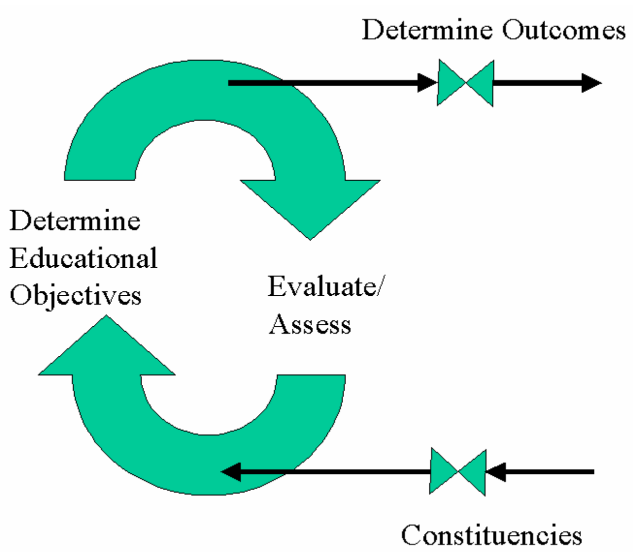

FIGURE 1
SCHEMATIC FOR THE INPUT FROM CONSTITUENCIES AND THE OUTPUT INTO THE EXPECTED OUTCOMES LOOP

PROGRAM OUTCOMES

The achievement of each program outcome is important to the mission of the institution and the objectives of the program [6]. In Figure 2 (Appendix 2, back of paper), the second loop (or the outcomes assessment loop) is presented in flowchart fashion.

The constituencies provide input on the objectives and this information is incorporated into the determination of the outcomes (Table 3) that are required to achieve these objectives. The remainder of the loop is composed of the assessment and evaluation of the achievement of the outcomes. This information is then incorporated into the student interface block, which includes classroom/laboratory instruction, research projects, advising, mentoring, professional society interaction and informal contact.

TABLE 3
PROGRAM OUTCOMES RELATIVE TO THE
PROGRAM EDUCATIONAL OBJECTIVES

Over the course of their studies, graduates from the chemical engineering program shall have demonstrated the following outcomes:

1. An ability to apply the knowledge of mathematics, science (especially chemistry), and engineering
2. An ability to design and conduct experiments, as well as to analyze and interpret data
   a. to incorporate the knowledge gained from experimentation and the literature into computer models, steady state and dynamic
3. An ability to develop and design a system, unit operation, or process to meet desired or anticipated needs, including:
   a. the ability to compose a process flow diagram and understand a piping and instrumentation diagram
4. The ability to function effectively in a team setting
   a. program related teams for projects and research
   b. multi-disciplinary teams
5. The ability to identify, formulate, and solve chemical engineering problems in a wide range of areas, including:
   a. environmental, health, and safety
   b. biochemical/biomedical
   c. refining/chemical processing
   d. pollution prevention and remediation
6. An understanding of professional and ethical responsibility
7. An ability to communicate effectively and to use current computer tools to present complicated concepts in a lucid manner
8. A knowledge of contemporary and societal issues and an appreciation of the impact of engineering solutions in a global context
9. A recognition of the need for continual self-renewal and the ability to engage in life-long learning

ASSESSMENT

Historically, evaluations and feedback from constituencies were always an important part of the program. This was evidenced in the 1990's [2-4] by the incorporation of advanced software into the curriculum as well as the introduction of several biotechnology classes on the undergraduate and graduate level. However, prior to EC 2000, the assessment and the closing of the loop was accomplished in an effective, but less structured format.

Consequently, in the past several years, there has been a significant effort by faculty and administration to implement the provisions of EC2000 (now using the EC 2003/2004 cycle information). In terms of an assessment strategy, the procedures in-place and those being developed are listed in Table 4. These correspond to Criteria 2 (Objectives) and Criteria 3 (Outcomes). The distinction is broadly made in terms of extramural data (Criteria 2) versus intramural data (Criteria 3).

Prior to the adoption of the structured assessment process described in the 2002 self-study of the chemical engineering program, assessment and program changes would be based on feedback from students via evaluation forms coupled with additional information from constituencies. The School of Engineering Board of Advisors, the newly formed Chemical Engineering Advisory Group, student full-time employers, co-op employers, independent study/ work-study advisors, graduate school recruiters, and faculty all provided information that was evaluated and incorporated as appropriate. Most of this process has been organized into a set of assessment tools.

These tools are described in Table 4 and correspond to the numbering system used by Rogers [8]. Felder and Brent [11] describe a similar set of tools.

TABLE 4
CHEMICAL ENGINEERING PROGRAM ASSESSMENT PROCESSES

1. Written Surveys and Questionnaires - opinion based
   - Course assessment surveys (filled out by students)
   - Faculty course assessment surveys
   - Faculty evaluations (currently not used for program assessment)
   - Alumni surveys
   - Employer surveys
   - Senior project evaluator surveys
   - Board of Advisors surveys
2. Exit and other interviews
   - Interview with advisor – portion of the exit interview
   - Written exit interviews (seniors - after 6 months)
3. Commercial, norm-referenced standardized examinations
   - FE exam – not taken by many ChE students
4. Locally developed examinations
   - Process design of "black book" (capstone design classes - per FIE1997 and FIE 2002 papers)
5. Archival Records
   - Transcripts and student advising files
   - Senior project (video, poster and report)
   - Research reports & project write-ups
6. Focus Groups
   - Collagen Research Group [5]
   - Student Organizations (AIChE, ACS, ISPE)
   - Chemical Engineering Advisory Group
7. Portfolios
   - *not formally practiced; closest items are:*
   - Student research papers, posters, and presentations are archived
   - Resumes are posted
   - Samples of student work kept with each course file
8. Simulations – competency based measures gauging performance in a real world setting
   - Case studies are incorporated throughout the program; capstone design classes
     - Students are assigned processes that required them to develop a design package (what is called a "black book" in industry)
9. Performance Appraisals
   - Cooperative education performance appraisals
   - Internships appraisals
   - Research collaborator appraisals
10. External Examiner
    - Adjunct professors on the ChE staff (from regional universities)
      - *- not now formally involved in assessment*
    - Widener faculty serve as outside guest reviewers for other regional chemical engineering programs
      - *- ChE faculty will consider reciprocity*
11. Oral Examinations
    - Course based orals – chemical engineering laboratory courses, capstone design class, values seminar
12. Behavioral Observations
    - Laboratory courses and senior projects offer opportunities to observe behavior
      - *- not currently used for assessment*
13. Senior Competency Testing (comprehensive 24 hr test)
    - Exam developed by Chemical Engineering Advisory Group
14. Student Contests – (annual undergraduate)
    - AIChE National Poster Contest
    - AIChE Student Regional Meeting
    - National Engineers Week Paper Contest
    - AIChE Zeisberg Competition
    - ACS Chromatography Forum
    - Others (Widener not participating every year)
      - AWMA Paper Contest
      - ISPE Poster Contest
      - MRS Paper Contest
      - AIChE Division Specific Contests
15. Research Groups (reports, reviews by sponsors – no formal interviews yet)
    - Collagen Research Group (since 1995 about 50 undergraduate students participating)
    - USDA - (2-3 undergraduates participating in protein research)
    - Industrial Based Research Projects [3, 10]

Table 4, continued

16. Student Presentations (intramural – other than above)
    Widener University Honors Week (~ 5 students/y)
17. Chemical Engineering Advisory Group [7]
    Interact with students at advisory group meetings and via joint projects (mentoring opportunities)
    Opinions via discussions (& sometimes surveys) re ChE program specifics

COMPREHENSIVE TESTING -INITIAL EXPERIMENT

In addition to the strategy listed above, a comprehensive competency test is administered as part of the final capstone design class. Currently, this is unique to the chemical engineering program. The faculty in the other engineering programs are considering this approach; however, they currently use the results of the FE test for similar data on achievement of outcomes.

In the initial trial in May 2003, the Chemical Engineering Advisory Group provided questions and suggested solutions for the test. Five questions were developed, each requiring about two pages of description and problem statement. The author graded the test based on the suggested solutions and procedures.

There has been some discussion of this approach in various technical society meetings and in the literature [9]. The advisors used the chemical engineering program outcomes to develop five questions, which were open ended and comprehensive. Using the outcomes indicated in Table 3, the test questions related to the program outcomes as indicated in the Table 5. This table also displays a portion of the mapping of the program and the ABET outcomes.

TABLE 5
MAPPING OF TEST QUESTIONS AND PROGRAM OUTCOMES

Questions	ABET Outcomes	Program Outcomes
1	a-c,d-k	1,2,7
2	a,b,c,e,f,h,i,j,k	1,5
3	a,b,c,e,f,h,i,j,k	1,3,5
4	a,b,c,e,f,h	2,3,5
5	c-k	6,8,9

Amore complete matrix is attached (appendix 3). Noticeably absent is the chemical engineering program outcome #4, which is *the ability to function in a team setting*.

The initial comprehensive test was given to the graduating class of 2003. This class was 25 % female and 25 % international students. This was a strong class academically and all of the students had gained employment or secured a graduate school position within a month of graduation. A portion of the class had job offers early in the spring, 2003 semester.

The grade point average for this class is presented in Table 6 along with some descriptive statistics. Faculty have the option of using the +/- system in grading and most take advantage of this.

TABLE 6
CLASS OF 2003 GPA STATISTICS

Mean	3.03
Standard Error	0.14
Median	3.01
Mode	2.4
Standard Deviation	0.51
Sample Variance	0.26
Kurtosis	-0.45
Skewness	0.21

Administering the Examination

The comprehensive competency test counts for 25 % of the grade in CHE-428. This class is Process Design - the second semester of the two-semester capstone design class. The other portion of the grade is the "black book" process design package that the students develop [2,4].

The following instructions were given to the students regarding the test.

Examination Instructions

Congratulations on reaching the end of your undergraduate chemical engineering education at Widener University. As indicated on our website and as required by ABET, we have developed a set of objectives and required outcomes for our graduates. The outcomes are attached at the back of this package.

When the ABET evaluators visited in November 2002, they reviewed course and curricular material, including student work. They were especially interested in material that demonstrated how our program incorporated and how we assessed the objectives and the required outcomes.

In order to provide an external assessment of our program we have invited chemical engineers from our Chemical Engineering Advisory Board to review our objectives and outcomes and then suggest problems that would be given to graduating seniors. This is a unique program in chemical engineering education. Along with your many other achievements, the class of 2003 will be remembered as the first group of Widener chemical engineering students to participate in this outside assessment.

Exam Specifics

You are required to work by yourself, using all the resources available at the university.

Answer all five questions with comprehensive answers including, as many angles to each problem that you feel are appropriate. It is suggested that you review the chemical engineering outcomes before tackling the questions.

You have 24 hours from the time you accept the test until you return it. Have any faculty member or secretary sign and note the date/time if no one is in the office.

Each problem has equivalent value and is worth 10 points.

Test Results

The results of the test are presented in Table 7. Most of the students used the complete 24-hour period to solve the examination. Each problem was graded out of 10 points and the scores of all the students for all the questions is about 74 % correct. This percentage is consistent with examinations in other upper level courses.

TABLE 7
RESULTS OF THE COMPREHENSIVE COMPETENCY TEST

Mean	7.38
Standard Error	0.24
Median	7.35
Mode	7.20
Standard Deviation	0.92
Sample Variance	0.84
Kurtosis	5.21
Skewness	-1.45
Range	4.20
Minimum	4.80
Maximum	9.00

The test scores correlate somewhat with GPA as indicated below:

Test Score = 0.78 [GPA] + 5.2
$R^2 = 0.49$

A breakdown of the performance on each of the questions is provided below along with the topic relating to each.

Question (1)

Topic: development of processing options in a chemical plant based on a variety of real world considerations

Average Score	7.30
Standard Deviation	0.51

Question (2)

Topic: environmental problem relating to fuel consumption including environmental, developmental, societal, and ethical issues

Average Score	6.96
Standard Deviation	2.17

Question (3)

Topic: development of the optimum design, control and operating strategy for a complex reactor system includes mass and heat transfer as well as kinetics and safety issues

Average Score	7.25
Standard Deviation	0.78

Question (4)

Topic: rating the performance of an existing separation system, performance of a hazard analysis and development of an operating strategy and corrective design

Average Score	7.54
Standard Deviation	0.95

Question (5)

Topic: assessing the societal implications of a given design given feedback from the public on the design

Average Score	7.86
Standard Deviation	1.06

CONCLUSIONS FROM THE COMPREHENSIVE TEST

All of the questions were very open ended and the students did an effective job in analyzing the problem and formulating a satisfactory answer. Most students took advantage of the ability to use the library, simulation packages (HYSYS, STELLA), EXCEL, and word processing in order to develop a solution. The scores were consistent across the five questions although it was evident that Question # 2 gave the most difficulty. This question was the least well defined of all the questions and required more analysis by the students than what was immediately obvious.

Conversely, when the students were asked for a response to a particular situation in which a significant amount of information was given (as in Question # 5) their answers were more comprehensive and covered the important areas.

RECOMMENDATIONS

The initial trial of the comprehensive competency test was successful in that the students demonstrated a good understanding of complex, open-ended questions and that, overall, the outcomes are being met. Additionally, the involvement of the external advisory board added a real-world perspective to the questions. Many of the problems provided were representative of situations that they have encountered in industry.

It is apparent that the more open-ended the problem, the more difficulty students have with it. The test will be repeated for the class of 2004 and the data presented to the chemical engineering faculty for inclusion in the assessment process.

Further information on the process and the results are available from the author. It may be feasible (and desirable) to coordinate efforts on comprehensive testing among several universities. Interested chemical engineering faculty should contact the author.

ACKNOWLEDGEMENTS

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APPENDIX 1

Program Outcomes vis-a-vis Program Objectives

Program Outcome		Program Objectives			Key Features
		OBJ [A] Broad Base	OBJ [B] Life-Long	OBJ [C] Ability to Excel	Oppt'y in Program
1.	an ability to apply the knowledge of mathematics, science (especially chemistry), and engineering	x	x	x	
2.	an ability to design and conduct experiments, as well as to analyze and interpret data	x		x	x
	a. to incorporate the knowledge gained from experimentation and the literature into computer models, steady-state and dynamic	x		x	x
3.	an ability to develop and design a system, unit operation, or process to meet desired or anticipated needs, including:	x		x	x
	a. the ability to compose a process flow diagram and understand a piping and instrumentation diagram	x		x	x
4.	the ability to function effectively in a team setting				
	a. program related teams for projects and research	x	x	x	x
	b. multi-disciplinary teams	x	x	x	x
5.	the ability to identify, formulate, and solve chemical engineering problems in a wide range of areas, including:	x	x	x	
	a. environmental, health, and safety	x	x	x	
	b. biochemical/biomedical	x	x	x	
	c. refining/chemical processing	x			
	d. pollution prevention and remediation	x		x	x
6.	an understanding of professional and ethical responsibility	x	x		
7.	an ability to communicate effectively and to use current computer tools to present complicated concepts in a lucid manner	x	x	x	x
8.	a knowledge of contemporary and societal issues and an appreciation of the impact of engineering solutions in a global context	x	x	x	x
9.	a recognition of the need for continual self-renewal and the ability to engage in life-long learning		x		

APPENDIX 2

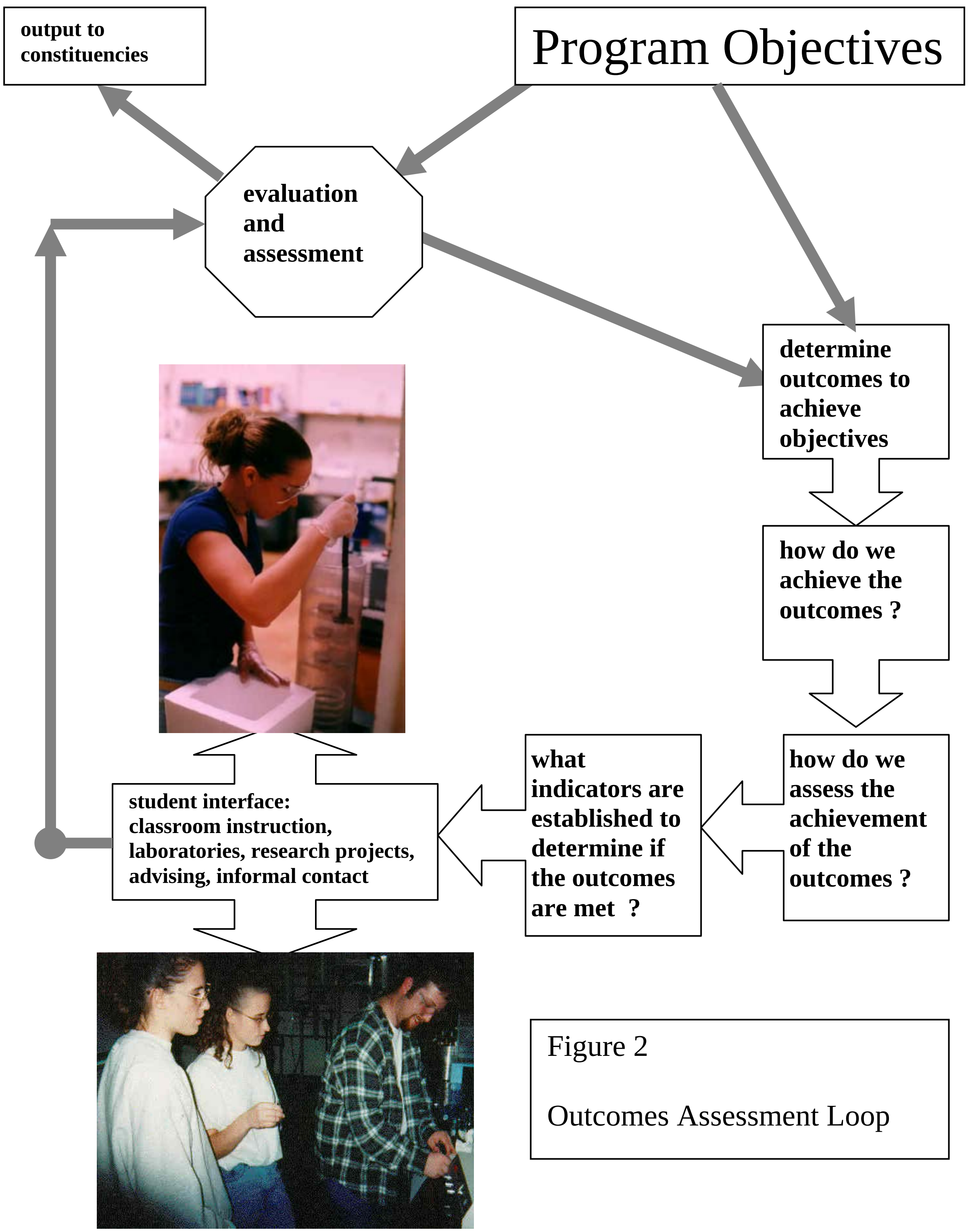

Figure 2

Outcomes Assessment Loop

APPENDIX 3

Mapping of ABET Outcomes with the Program Outcomes

	Program Outcomes	ABET Desired Outcomes										
		[a]	[b]	[c]	[d]	[e]	[f]	[g]	[h]	[I]	[j]	[k]
1.	an ability to apply the knowledge of mathematics, science (especially chemistry), and engineering	x	x	x		x			x	x	x	x
2.	an ability to design and conduct experiments, as well as to analyze and interpret data	x	x									
	a. to incorporate the knowledge gained from experimentation and the literature into computer models, steady-state and dynamic	x	x									
3.	an ability to develop and design a system, unit operation, or process to meet desired or anticipated needs, including:			x		x	x		x			
	a. the ability to compose a process flow diagram and understand a piping and instrumentation diagram			x			x					
4.	the ability to function effectively in a team setting			x	x			x				
	a. program related teams for projects and research			x	x			x				
	b. multi-disciplinary teams				x			x				
5.	the ability to identify, formulate, and solve chemical engineering problems in a wide range of areas, including:			x		x	x					
	a. environmental, health, and safety				x	x	x					
	b. biochemical/biomedical				x	x	x					
	c. refining/chemical processing					x	x					
	d. pollution prevention and remediation				x	x	x					
6.	an understanding of professional and ethical responsibility			x	x	x	x		x		x	
7.	an ability to communicate effectively and to use current computer tools to present complicated concepts in a lucid manner					x	x	x			x	x
8.	a knowledge of contemporary and societal issues and appreciation of the impact of engineering solutions in a global context				x	x	x	x	x		x	
9.	a recognition of the need for continual self-renewal and the ability to engage in life-long learning					x		x	x	x	x	x