Integrated Curricula in the SUCCEED Coalition

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I. Abstract

The SUCCEED Coalition supported two attempts at developing and implementing integrated curricula. The first of these was the Integrated Mathematics, Physics, Engineering, and Chemistry (IMPEC) program at NC State, which used a fully-integrated team-taught set of courses. A second program piloted at the University of Florida retained traditional courses with department control, but the faculty from Mathematics, Physics, Chemistry, and Engineering collaborated to coordinate their curricula so that concepts or topics could span more than one class. Both programs included other aspects of skill development. This paper summarizes the assessment data from both programs and recommends a path forward for integrated curricula in engineering education.

II. Objectives of SUCCEED integrated curricula

Traditional engineering curricula are highly compartmentalized. Fundamental mathematics and science courses and engineering courses are generally self-contained, with few connections being made to related courses in other disciplines or even the same discipline. Real engineering problems, on the other hand, invariably involve information and skills associated with a variety of engineering, mathematics, and physical science courses. When students do not understand the interrelations between different subjects, they tend to be less motivated to learn new subject matter and consequently less able to solve realistic problems. Recognizing this problem, the past decade has seen several universities develop first-year engineering curricula that include multidisciplinary integration.[1,2] A previous paper from a multi-coalition collaboration provides a comprehensive review of the pros and cons of curriculum integration.[3]

The NSF-funded Southeastern University and College Coalition for Engineering Education (**SUCCEED)** was formed in 1992 by eight prominent and diverse southeastern colleges of engineering with a shared vision of creating sustainable engineering education reform having national impact. This vision was articulated through the definition of a curriculum model based on the desired attributes of engineering graduates. It was desired that the graduates of this curriculum be technically competent, critical and creative thinkers, life-long learners, effective communicators, team players, and globally aware. They should understand process and systems design and integration, display high ethical standards, and appreciate the social context of engineering and industry business practices. The curriculum model was designed to develop these qualities through changes in the curriculum content, structure, delivery, and management. A key change element in the curriculum content and structure was subject integration (knowledge

structure and information processing) that included early introduction to the engineering thought process and explicit success skill development. An examination of freshmen retention data across the curriculum suggested that integration of the first year would provide the most impact. Furthermore, it was believed that integration of the freshmen year might be easily implemented given the common subject material (i.e., mathematics, physics, chemistry, English) being taken by engineering students. Thus the SUCCEED Coalition embarked on a set of experiments in 1992 to explore different approaches to integrate the freshman year.

Coupling subject integration in the first year with an introduction to engineering was ideally suited for the Coalition's program given the large resources required to conduct large-scale experiments, the availability of a multiple-campus laboratory to determine robustness, the extended period of funding, and the visibility of this NSF program. The approaches to integration studied by the coalitions required building teams of faculty from multiple disciplines and assessment experts to evaluate the program impact and designing and equipping suitable classroom space. This paper reports on two such programs—one developed at North Carolina State University and another developed at the University of Florida. The 2-semester NC State program, designated as IMPEC (Integrated Mathematics, Physics, Engineering, and Chemistry), comprised Calculus I and II, Physics I, Chemistry I, and a one-credit engineering course in each semester that provided engineering context for the material presented in the math and science courses. The curriculum was team-taught by professors from each of the disciplines involved using a wide variety of pedagogically sound principles and methods. [4,5,6,7]

The goal of IMPEC was not to develop a curriculum that could be implemented in its entirety for the entire entering freshman class: the required commitment of space, equipment, and faculty time made such a goal unrealistic. Rather, the goal was to develop a best-case scenario for the first year of engineering—to see what could be accomplished if dedicated instructors put everything they knew about effective pedagogy into a program. If the program proved to be successful, the next step would be gradually to introduce elements of IMPEC into the mainstream freshman program, trying to get the latter to evolve to something resembling IMPEC to the greatest extent possible. In its final form, IMPEC was delivered for two consecutive years.

The University of Florida's Knowledge Studio was also supported by SUCCEED for two years. In Knowledge Studio, the first two years of engineering education were integrated in such a way as to maintain departmental structure. Curriculum integration was achieved through cooperation of a faculty team representing Mathematics, Chemistry, Physics, Engineering, and consultants from the College of Education. A central "Knowledge Studio" served as a common space for all discussion sections. It was intended to help students accelerate their learning as a cohort working in a familiar environment and using a common set of computer tools. The cooperative learning instructional model served as the basis of the teaching philosophy used throughout the program.

Whereas IMPEC was never intended to serve a large fraction of engineering freshmen in its complete form, the Knowledge Studio sought to achieve the benefits of an integrated curriculum in a less ambitious way that had the potential of serving more students. The two year project included the following courses: Calculus I, II, III and Differential Equations, General Chemistry I and II, and Physics I and II and a Freshman Engineering class. The project started in Fall 94 with

planning, developing course structures and enlisting students. There were 92 students entered into the program starting Fall of 95.

III. Structure of IMPEC

Courses

- **MA 141—Analytic Geometry and Calculus I** (Fall, 4 credits, 5 contact hours per week).
  MA 241—Analytic Geometry and Calculus II (Spring, 4 credits, 5 contact hours / week).
  Text: D. Hughes-Hallet, Gleason, *et al*., *Calculus*, New York, John Wiley & Sons (1994).

The IMPEC mathematics course sequence was nontraditional in several respects. It derived its instructional philosophy from the text being used, which is generally referred to as the Harvard text. Loved by many mathematicians, hated by others, the text is a radical departure from the usual encyclopedic clone. It emphasizes a true understanding of the concepts, as opposed to learning drills and prescriptions, via the "rule of three," which states that every topic should be presented geometrically, numerically, and algebraically. Additionally, it emphasizes the "way of Archimedes"—formal definitions and procedures evolving from the investigation of practical problems. Extensive student use in the course of MAPLE, a symbolic mathematical program, served to integrate and reinforce these instructional philosophies. MAPLE was used as a tool to encourage experimentation with everyday applications to which the students easily relate, many of which could not be otherwise assigned due to their algebraic complexity. The strongly applied nature of the text made the integration of calculus with science and engineering considerably easier than it would be with a conventional calculus text.

- **CH 101—General Chemistry I** (Fall, 3 credits, 3 contact hours per week).
  CH 121—General Chemistry Laboratory (Fall, 1 credit, 3 contact hours per week).
  Text: Masterson and Hurley, *Chemistry: Principles and Reactions*, Fort Worth, Saunders College Publishing, 1993.
  Supplementary instructional software: *Exploring Chemistry* and *Introduction to General Chemistry*, distributed by Falcon Software, Inc., Wentworth, NH 03282.

The chemistry portion of IMPEC included several features that are not part of the typical college chemistry experience, specifically, interactive computer simulations of experiments and problem-solving exercises done by groups in class. The students were routinely called on to dialogue with the instructor to provide evidence of their conceptual understanding. Emphasis was placed on questions that involved the higher-order thinking skills of analysis, synthesis, and evaluation. Students were frequently challenged with questions such as "What if you changed this?" or "How would you expect this to affect the results?" Many demonstrations were conducted, after which the students were required to discuss and write explanations for what they saw and did.

The lecture and lab portions of the chemistry course were taught by the same instructor in another major departure from the usual college chemistry experience. The students were not given detailed procedures for most laboratory exercises but had to work out the details themselves in their teams. The instructor only provided information the students could not have been expected

to know about the reactive systems they were analyzing and other information related to laboratory safety. At the conclusion of each experiment, the students prepared a major paper on their experiments. They were initially hesitant about this way of working, since they were accustomed to following "recipes" in most of their prior lab experiences, but by the end of the semester they were remarkably confident and comfortable with the process. The teaching assistant working with the class—who also taught traditional freshman chemistry labs—expressed amazement at the superior ability of the IMPEC students to "do chemistry," demonstrating true conceptual understanding and not just the ability to perform prescribed calculations.

- **PY 205—Physics for Engineers and Scientists I (Mechanics)**. (Spring, 4 credits, 5 contact hours per week).

  Text: *Understanding Basic Mechanics*, Frederick Reif, John Wiley and Sons, Inc., 1995.

  Supplementary instructional software:
  Interactive Physics, Knowledge Revolution, San Mateo, CA 94402
  VideoPoint, Lenox Softworks, Lenox, MA 01240
  Motion, Vernier Software, Portland OR
  Graphs and Tracks, Physics Academic Software, Raleigh, NC 27695

The physics portion of IMPEC was taught using highly interactive lecture-lean methods. Variations on ideas in Workshop Physics[8] and Studio Physics[9] were used to create hands-on exercises to illustrate physical concepts. Flexible microcomputer-based laboratory tools were used for acquiring, reducing, and real-time plotting of real-world data, and computer simulations and spreadsheets were also used when appropriate. Homework and exam questions were frequently open-ended, demanding more than formula substitution for solutions.

- **E 497—Introduction to Engineering** (Fall/spring, 1 credit/semester, 2 contact hours/week).

  Text: R.B. Landis, *Studying Engineering*. Burbank, CA, Discovery Press, 1995.

  Activities in the engineering courses included

  - in-class exercises and homework assignments that involved applications of calculus, chemistry, and physics to engineering problems;
  - lectures and workshops on study and time-management skills, word processing, other computer applications, technical writing, oral presentations, and presentation graphics;
  - assignments that involved summarizing sections and doing several of the chapter-end exercises in the Landis text, writing paragraphs outlining and explaining their choices of major fields of study, and preparing resumes and cover letters requesting consideration for summer employment;
  - a major design project in each semester
  - orientation presentations by representatives of different engineering departments;
  - field trips to engineering laboratories and a construction site, and guest presentations by recent engineering graduates.

In the fall course, teams of students designed a shower in a recreational vehicle equipped with a

propane-fired water heater. They formulated engineering specifications for the product, listed the roles that different branches of engineering would play in its design and development, and outlined possible applications to the design process of mathematical and scientific concepts presented in the concurrent IMPEC courses. The teams had to submit two preliminary drafts and a final written report, and also had to give oral presentations using PowerPoint. In the spring, teams carried out a semester-long project that had the automobile as its theme. The teams visited the shop of a local race car driver and got information about design and safety practices on the field trip and also in library research. They then solved problems involving vehicular motion that incorporated material from the physics and mathematics courses, worked in teams to design, build, and analyze models of an automobile steering and suspension system, and again prepared and delivered written and oral project reports.

Advising

The IMPEC chemistry instructor (who was simultaneously serving as an academic advisor for the N.C. State First-Year College) served as the principal academic advisor for the students, providing them with information about the campus, helping them with administrative issues such as registration, and counseling them on study skills, test-taking skills, time management, and social and emotional issues. In addition, he monitored their workload as closely as possible and intervened at times to reduce it if he felt it appropriate to do so.

Recruitment and Enrollment

In May before each of the two years of IMPEC, letters were mailed to about 400 admitted engineering students, telling them about IMPEC and inviting them to attend either of two sessions scheduled during the campus freshman orientation program in June. Over 100 students attended the sessions. The IMPEC faculty members described the principal features and requirements of the curriculum. Students who wished to participate signed forms expressing their desire to do so and at the same time giving permission to access their records for assessment purposes. The forms also requested demographic information and asked whether or not the students expected to receive advanced placement credit for any of the subjects included in IMPEC. (If advanced placement credit had been received for any IMPEC course, the student had to forego the credit to participate.) Over 80 students signed the forms each year.

The goal of the recruitment effort was to form a 36-person class (the capacity of the IMPEC classroom) with a demographic profile that closely matched the profile of the entering freshman engineering class and to constitute a matched control group from among the volunteers not selected to participate. Following the orientation sessions in the first year, all four African-American students who applied were admitted (disproportionately few African-Americans had come to the orientation sessions) and 32 other students were chosen to participate by stratified random selection. A matched 31-member control group was formed from the remaining volunteers. A control group was not selected in the second year, but the performance of the IMPEC students was compared with that of all engineering freshmen who did not go through IMPEC.

Classroom

With the exception of CH 121 (a wet chemistry laboratory course), all IMPEC classes took place in a classroom equipped with twelve 3-person tables, 25 IBM PC's, and workshop physics equipment. The classroom was not an optimal instructional facility, to say the least: it was crowded, the instructor could not easily circulate through it, and until late in the year the students had to look over or around the computer monitors to see the instructor.

Instructional Format

Most of every morning of the week was blocked out for IMPEC courses. A nominal schedule specified which courses (math, chemistry/physics, and engineering) met during which hours, but the schedule was adjusted as needed according to which topics were to be emphasized in a given week. Most class periods were taught by individual IMPEC faculty members, but several times during each semester "workshops" on specific topics (e.g. spreadsheeting, statistical analysis, and rotational motion) were team-taught by the full faculty. Weekly homework assignments, four class tests, and a final examination were given in each of the four mathematics and science courses. Weekly homework assignments were given for the first half of each semester in the engineering courses, and progress reports on the engineering projects were due several times during the second half of each semester. The IMPEC faculty met for 30–60 minutes each week to review the previous week's progress and plan the homework assignments and class activities for the coming week.

The course made extensive use of cooperative (team-based) learning, both in and out of class. The students filled out questionnaires on the first day of class that provided demographic and scholastic aptitude information, class schedules, and extracurricular time commitments. This information was used to form teams of three or four, with each team having a distribution in ability levels among its members and common times for meeting outside class. Some but not all of the homework assignments and the engineering course projects were done by the teams. In addition, in-class exercises done by different teams of three were interspersed throughout each class period. One math test and one science test were taken by student pairs, formed to be heterogeneous in ability, and the remaining tests (including the final examinations) were taken individually.

On each homework assignment, the teams designated a coordinator, recorder, checker, and monitor. The monitor's task was to summarize what the team had done effectively, what problems it had encountered (related to teamwork and time management, not technical problems), and what the team members would attempt to do differently on the next assignment. The team roles rotated with each assignment.

Course handouts, assignments, and revised schedules were delivered through a World Wide Web site. Most students felt no need to print the materials since they could always consult the Web site at any time from computers in the classroom or their dormitories. Distributing the course materials in this manner was no more time-consuming than the traditional process of making paper copies, and the inevitable last-minute changes were relatively painless.

IV. Assessment of IMPEC

Data were compiled for IMPEC students and (unless otherwise noted) students in two comparison groups. The term "Control Group" refers to a group of 31 students who volunteered for IMPEC in the first year but were not selected due to the capacity of the IMPEC classroom. They matched the IMPEC group in pre-college performance measures, but did not include any African-American students. The term "E100 group" refers to the students in the regular freshman engineering course, including nine African-American students. (Most of the other African-American students in the freshman class were in a separate program designed specifically for minorities.)

The data compiled included the following:

- *pre-admission data* (predicted grade-point average, SAT scores).
- *responses to the Pittsburgh Freshman Engineering Attitude Survey* (beginning and end of the fall semester, and for IMPEC only, end of the second semester). An instrument developed at the University of Pittsburgh that assesses attitudes toward engineering as a curriculum and career, self-reported confidence levels in core freshman-year subjects, and in the post-survey, attitudes toward the freshman year experience.
- *Force Concept Inventory scores* (IMPEC only, beginning and end of second semester). A widely used instrument that assesses conceptual understanding of mechanics.
- *performance on common final exam problems in calculus, chemistry, and physics courses*.
- *responses to open-ended questions on midsemester and end-of-semester surveys* (IMPEC only).
- *Written and oral engineering project reports* (IMPEC only)
- *Passing rates in calculus and science courses included in IMPEC.*
- *Overall GPA in the first year.*
- *Retention in engineering through the first year*.

Following is a summary of the principal results. Additional details are given by Felder *et al*.[4–7] In the first year of IMPEC,

- The pass rate (C or better) in the core courses was significantly higher for IMPEC students (69%) than for students in the control group (52%) or in E100 (52%). Roughly equal percentages of all three groups (roughly 80%) remained as declared engineering majors at the beginning of the Fall 1996 semester, but fewer of the IMPEC students were in academic difficulty.
- IMPEC students did as well as or better than students in the control groups on common final examination questions in calculus, chemistry, and physics courses. The IMPEC students also did well on questions that tested them for the deeper levels of comprehension of principles that were among IMPEC's principal objectives. (There was no way of including such questions on the final examinations in the traditionally-taught courses.)
- The IMPEC students' performance on the Force Concept Inventory was substantially better

than the average performance of students at other institutions who had taken a traditionally-taught lecture-based mechanics course.

- When the students were asked to indicate their agreement or disagreement with the statement, "I expect engineering will be a rewarding career," the IMPEC students and the control and E100 groups all strongly agreed at the beginning of the fall semester. A decline in the average level of agreement would be expected during the first semester, since most entering students have little or no idea of what engineering is and some find that they are poorly suited to it. At the end of the semester, the average levels of agreement for the control and E100 groups declined two to four times more sharply than that of the IMPEC students, which only declined slightly.
- The IMPEC students' level of agreement with the statement, "The engineering course helped me know whether I want to major in engineering," was significantly greater than the levels of agreement of the control group and the E100 group.
- To a much greater extent than students in the regular freshman engineering course, the IMPEC students credited their engineering course with helping them improve their skills in problem solving, studying, teamwork, time management, reading, writing, speaking, and computing.
- The IMPEC students' self-rated confidence in their abilities in chemistry, engineering, computing, speaking, and writing increased sharply in the first semester. The confidence levels of the control students in the same areas declined (dramatically in chemistry and writing, slightly in engineering, computing, and speaking). The confidence levels of the E100 students either declined sharply (in chemistry), stayed roughly the same (in engineering), or increased slightly (in computing, speaking, and writing).
- The IMPEC students slightly increased their confidence in their calculus ability in the first semester. The E100 students (a number of whom had taken advanced placement calculus in high school) maintained but did not increase their confidence, and the control group confidence sharply declined.
- The IMPEC students' confidence in physics increased slightly in the first semester, which is interesting since none of them took a physics course that semester. It may be that their increased confidence in other areas simply made them more confident of their problem-solving abilities in general, regardless of the subject, or that the emphasis on applications in the Harvard Calculus approach increased their confidence in their ability to deal with physics problems. Their confidence in physics increased sharply after they took the physics course in the second semester.

The positive attitudes of the IMPEC students to almost every aspect of the course are all the more impressive considering that they found the curriculum more demanding than the control and E100 groups found *their* freshman year curricula (as evidenced by their responses to certain questions on the Pittsburgh Freshman Engineering Attitude Survey).

V. Structure of the University of Florida's Knowledge Studio

In the Knowledge Studio program, the separate courses are taught and controlled by individual

departments in their traditional single course, non-integrated format, while the sequence of topics and format for delivery are determined collaboratively. The instruction made extensive use of active and cooperative learning and instructional technology. To help prepare the faculty for these non-traditional teaching methods, SUCCEED hosted Dr. Richard Felder and Dr. Rebecca Brent's "Effective Teaching Workshop." Most of the participating faculty (including all faculty members teaching first-semester courses) and teaching assistants attended.

Implementation

The Knowledge Studio curriculum is shown in Table 1.

Table 1. Knowledge Studio curriculum.

Fall 1995	**Spring 1996**
Analytical Geometry and Calculus I (4 credits)	Analytical Geometry and Calculus II (4 credits)
General Chemistry I with Lab (4 credits)	General Chemistry II with Lab (4 credits) (optional - some majors do not require)
Introduction to Engineering (1 credit)	Physics I with Calculus with Lab (4 credits)
General Education class(es) (varies)	General Education class(es) (varies)

Fall 1996	**Spring 1997**
Analytical Geometry and Calculus III (4 credits)	Differential Equations (3 credits)
Physics II with Calculus with Lab (4 credits)	Engineering courses determined by major
Biology for Engineers (3 credits) (optional - some majors do not require)	General Education class(es) (varies)
General Education class(es) (varies)	

Additional structure was provided through a number of orientation activities including student advising, registration assistance, and placement exam study sessions. Students also participated in a time management exercise before the start of the semester. Early design and introduction to the engineering thought process were accomplished by the use of application-oriented examples in the mathematics coursework and by the inclusion of Introduction to Engineering in the first semester. The latter class exposed students to all undergraduate engineering programs offered at UF through hands-on experiments and design activities.[10]

The program was designed for sustainability and exportability. By leaving traditional departmental

structures intact, implementation cost and "turf" conflicts were minimized. Another feature which promoted sustainability was the recognition that at a school the size of the University of Florida, some large lecture classes are inevitable but can be improved and supplemented by studio work in smaller groups.

The laboratory sessions were a significant departure from standard laboratories and recitations. In the chemistry laboratory, students used the Texas Instruments TI-85 graphing calculator and its Computer-Based Laboratory (CBL) interface to obtain and analyze real-time data from various instruments. In the Mathematics laboratory sessions, MAPLE symbolic mathematic software was used. The concept of the Knowledge Studio workspace was an adaptation of an idea already being used successfully in upper division courses. A donation from Sun Microsystems provided 15 workstations to establish the space. The workstations had the MAPLE symbolic mathematic software installed that was used for calculus as well as other application software and equipment. The space served as a common forum for instruction, lab meetings, and cooperative work sessions.

Logistics

Faculty willing to experiment with new teaching methods were selected at the project's inception in Summer 1993 for each required math, chemistry, physics, and biology course in the program. Additional faculty included three professors from the College of Engineering to evaluate engineering content and one from the College of Education to coordinate assessment and advise the project faculty on instructional methods. Individual courses were modified, technology was investigated and new methods were preliminarily inserted into existing courses for evaluation in Fall 1993 and Spring 1994.

Program participants were recruited from a mailing list of all applicants to the University of Florida for Fall 1995 admission who indicated an interest in majoring in engineering. Of 1068 students on that list, 534 were randomly selected to receive an invitation to participate in the program. The program was designed to accommodate 120 students. Only 93 students actually entered the program. The most common reason for a student to be disqualified from program participation was the requirement that participants be ready to enter Calculus I directly from high school—many students were unprepared and opted to take Pre-Calculus first.

VI. Assessment of the Knowledge Studio

Control populations were constituted for each course to match the Knowledge Studio population as closely as possible. Since the Knowledge Studio accepted all applicants, a control group of students who had volunteered for the program but were not admitted could not be formed.

The data compiled included the following:

- *pre-admission data* (SAT scores, SAT II scores).
- *responses to the Pittsburgh Freshman Engineering Attitude Survey*[11] (beginning and end of the first semester). An instrument developed at the University of Pittsburgh that assesses

attitudes toward engineering as a curriculum and career, self-reported confidence levels in core freshman-year subjects, and in the post-survey, attitudes toward the freshman year experience. Control group: other students taking Introduction to Engineering.

- *Force Concept Inventory scores* (Knowledge Studio and control, beginning and end of physics course). A widely used instrument that assesses conceptual understanding of mechanics.[12]
- *Myers-Briggs Type Inventory* was administered in Fall 1995 to the Knowledge Studio group
- *performance on common final exam and course grades in chemistry*. The control group was a group of students in the same chemistry lecture but a traditional laboratory.
- *performance on common final exam in mathematics*.
- *Various measures of success using student record data at the completion of the two-year program.* The control population was a group of over 200 students who entered the university at a similar time with similar backgrounds.

Following is a summary of the principal assessment results for the Knowledge Studio program.

- Knowledge Studio participants were at an academic disadvantage relative to most control groups. Specifically, their SAT math scores were half a standard deviation (50 points) below the average for the University of Florida.
- Chemistry final exam grade distribution showed that Knowledge Studio students had double the failure rate of the control group. The control group had four times the percentage of A's. The instructors believed that being forced to give a common exam caused significant difficulties for the participants, who were used to a different format of test.
- Chemistry course grades: in spite of the terrible performance of Knowledge Studio participants on the final exam, there was no statistically significant difference in the distribution of final course grades.
- SAT II Chemistry placement exam scores had no relationship to Chemistry success
- Mathematics final exam grade distribution showed no significant difference between Knowledge Studio and control (control grades were observed to be 10 points higher). Again, using a common exam caused difficulties for the participants, who were used to a different format of test.
- At the completion of the two-year program, the Knowledge Studio group had a higher percentage of students still in engineering (60% to 50%), but a statistical test found this difference not to be significant. A significant difference existed between the Knowledge Studio and control groups for males still enrolled in engineering (66.7% to 53.0%) but the difference for females was not significant (39.2% to 38.6%). No significant difference was found between the retention of Knowledge Studio and control groups on the basis of race. At the completion of the two-year program, multiple regression showed Knowledge Studio GPAs in mathematics were significantly higher than those of the control group, Knowledge Studio GPAs in chemistry were significantly lower, and Knowledge Studio and control group overall GPA and GPA in physics were not significantly different.
- At the completion of the two-year program, the average number of times students withdrew from a course and the average number of failing grades were both lower for the Knowledge Studio group than for the control group. Neither difference was statistically significant.

VII. Long-term Effects of IMPEC and Knowledge Studio on Grades and Retention

Data from the SUCCEED longitudinal database[13] were used to match each student in the IMPEC program in with another N.C. State student who was not in IMPEC but had the same gender and ethnicity, major field of study, and similar SAT scores. Grade Point Average, graduation, and retention data for the experimental group (labeled IMPEC) and the control group (labeled Non-IMPEC) were obtained from the SUCCEED longitudinal database for the matched pairs. Retention rates (including students who graduated or were still enrolled in engineering) for the 1995 are cross-classified in Table 2. Retention rates for the 1996 cohorts are similarly shown in Table 3.

Table 2: Retention data for matched pairs of IMPEC and non-IMPEC students, 1995 cohort

	Non-IMPEC retained	**Non-IMPEC not retained**	**Total**
IMPEC retained	$n_{11} = 13$	$n_{12} = 9$	n_{1+} **= 22 (65%)**
IMPEC not retained	$n_{21} = 7$	$n_{22} = 5$	n_{2+} **= 12**
Total	N_{+1} = **20 (59%)**	n_{+2} **= 14**	n_{++} **= 34**

Table 3: Retention data for matched pairs of IMPEC and non-IMPEC students, 1996 cohort

	Non-IMPEC retained	**Non-IMPEC not retained**	**Total**
IMPEC retained	$n_{11} = 17$	$n_{12} = 6$	n_{1+} **= 23 (64%)**
IMPEC not retained	$n_{21} = 10$	$n_{22} = 3$	n_{2+} **= 13**
Total	N_{+1} = **27 (75%)**	n_{+2} **= 9**	n_{++} **= 36**

The McNemar Test for matched pairs[14] was used to test the difference in retention of the IMPEC (65% average for both cohorts) and non-IMPEC students (67% average for both cohorts). The difference in retention was not statistically significant. The difference in grade-point average was tested in a similar study using the dependent sample t-test, deleting pairs if either the IMPEC or non-IMPEC student left engineering. The mean GPA for the IMPEC group was 3.1 with standard deviation 0.47 and the mean GPA for the non-IMPEC group was 2.9 with standard deviation 0.60. The t-statistic for the 0.169 mean difference in sample means was 1.21, p=.237, so again the difference was not significant.

A study with the same protocol was used to investigate the benefit of the Knowledge Studio program. Again, the McNemar Test for matched pairs was used to test for marginal homogeneity for matched binary responses, and again, there the probability of retention (graduation or continued enrollment) in engineering was not significantly different for the Knowledge Studio (57% retention) and Non-Knowledge Studio (49% retention) groups. The mean GPA for the KS group was 3.0 with standard deviation 0.55, and that for the Non-KS group was 3.0 with standard deviation 0.64. The mean of the difference in sample means was 0.031, and the t-statistic was 0.18, p=.8578. There is essentially no difference between the sample means.

Table 4: Graduation/retention data for matched pairs of Knowledge Studio and Control students

	Control retained	Control not retained	Total
KS retained	$n_{11} = 21$	$n_{12} = 22$	n_{1+} **= 43 (57%)**
KS not retained	$n_{21} = 16$	$n_{22} = 16$	n_{2+} **= 32**
Total	n_{+1} **= 37 (49%)**	n_{+2} **= 38**	n_{++} **= 75**

Since the short-term assessment results for the Knowledge Studio reported in Section VI were mixed, it is not surprising that no long-term performance differences were found between participants in this program and the non-participant control group. On the other hand, the short-term outcomes for the IMPEC group were consistently more positive—significantly so in many cases—than those for the control groups, leading to a question about why the differences did not persist at a significant level through the subsequent three years.

One problem is that there were only 36 IMPEC students in each of the two years of the program, which alone would make it difficult to find statistically significant differences. Other problems have to do with the performance measures used as the basis of comparison between the two groups, and illustrate the difficulties of performing valid comparisons between experimental and traditional instructional programs.

Consider the variety of factors involved in attrition from engineering school. IMPEC and non-IMPEC students might have withdrawn for any of several reasons:

(1) Students were academically very weak and would not have been able to succeed in engineering regardless of how it were taught. Probably equal numbers of IMPEC and non-IMPEC students would fall in this category. The greater the number, the harder it would be to find a statistically significant difference between the two groups.

(2) The quality of the instruction in the first-year courses was so bad that students with the potential to succeed either flunked or decided to change to a curriculum where the teaching was better. The short-term assessment results (especially the data from the Pittsburgh attitude survey) suggest that none of the IMPEC first-year dropouts and most of the non-IMPEC first-year dropouts who were not in Category (1) were in this category.

(3) Having learned about what engineers actually do (which few, if any, entering freshmen know and almost equally few know after the traditional first year), students switched to a field in which they would be more comfortable pursuing a career. The short-term assessment data suggest that most of the IMPEC students and few of the non-IMPEC students not in Category (1) who dropped in the first year did so for this reason.

(4) Either because of poor instruction in Years 2-4 or because of a belated discovery of what engineers do, students failed or switched curricula after the first year. This category might include IMPEC and non-IMPEC students and would add to the difficulty of seeing a statistically significant difference.

IMPEC dropouts for Reason 2 would reflect poorly on the program, dropouts for Reason 3

would reflect well on it (since one of the objectives of the program is to give students a realistic picture of what engineers do), and dropouts for Reasons 1 and 4 would not really reflect on IMPEC in either direction. The same can be said of non-IMPEC dropouts with respect to the standard freshman curriculum. It would therefore be a mistake to draw any conclusions about program effectiveness from the lack of statistical significance of the overall retention differences (which lump all the dropouts together).

Problems also exist with the use of overall 4-year grade-point average as a basis of comparison of IMPEC and non-IMPEC students. First, the overall GPA is affected by many courses unrelated to the courses in the IMPEC curriculum, including general education courses, which would tend to dilute the differences in grades related to the differences between the two freshman curricula. A fairer test would be to look at grades in math, science, and engineering courses only.

Even then, however, there would be a problem. IMPEC was designed to help students develop higher-level thinking and problem-solving skills. Unfortunately, most science and engineering examinations never go far beyond problems that can be solved primarily by memorization and formula substitution, and the examinations in turn determine the course grades, which collectively determine the GPA. To learn whether IMPEC truly affected the quality of learning and skill development, examinations would have had to be given to both the experimental and the control groups that included problems requiring deep conceptual understanding of course material and ability to deal with open-ended problems. The IMPEC course examinations did have such problems, but it would not have been fair to include them in the traditional courses, which did not provide training in such exercises.

In hindsight, what should have been done would be to unofficially give control group students the same final examinations that the IMPEC students took and vice versa, probably paying both groups for their time. Unfortunately, this cannot be done retroactively for these students, so the long-range benefits of IMPEC must remain a subject of speculation. Future investigators who plan similar studies might do well to take a lesson from this experience.

VIII. The challenges of establishing an integrated curriculum

An integrated curriculum of the types implemented by SUCCEED can be a radical departure from the traditional freshman engineering curriculum in many respects, including a heavy reliance on active and cooperative learning as opposed to straight lecturing, the integration of subjects that are normally taught in isolation from one another, and a provision of explicit training in critical success skills. For institutions contemplating introducing elements of this nontraditional approach, we offer some suggestions about the challenges that are likely to arise and conditions favorable to overcoming them.

Student-related challenges. Many students—especially first-year students—can be expected to

- lack study skills, problem-solving skills, test-taking skills, team skills, and communication skills. These skills are important ingredients of success in all engineering curricula but are particularly crucial in experimental curricula; if skill training is not provided, frustration and

failure may result.

- feel resentment if they perceive that they have to do more than their classmates in a traditional curriculum. In many experimental curricula this perception is grounded in reality: professors often begin with unrealistic expectations of the students and/or serious underestimates of the amount of time required to complete the experimental assignments.
- dislike open-endedness and ambiguity, preferring everything to be black and white. In the view of these students, instructors' expectations should be clearly defined, and all information needed to complete all assignments should be explicitly presented in lectures. Moreover, all problems should have one and only one answer, which it is the instructor's responsibility to know and their job to find.
- resist mandatory group work. Relatively introverted students prefer to work alone, and bright students resent being slowed down and possibly having their grades lowered by academically weak or irresponsible teammates.
- being human, resist any change from what they are used to.

These problems are not insurmountable, but solving them takes time and practice. Unfortunately, since student evaluations are an important component of experimental program assessment and evaluation, the almost inevitable occurrence of the problems may be enough to doom fundamentally sound programs in their initial stages if the implementation is not done in a careful manner.

Faculty-related challenges. Curriculum integration requires instructors to do everything they would normally do when teaching a traditional class and much more in addition. Most professors

- don't welcome additional demands on their time, since they are already seriously overextended. They *really* don't like additional demands on their time for which they get no reward, tangible or otherwise.
- are reluctant to deviate from the standard course syllabus for fear the students will miss something important.
- feel uncomfortable about having someone from another discipline telling them anything about how they should teach their subject.
- have an unrealistic picture of the average skill levels of college freshmen and either set unattainable standards or set high but attainable standards and fail to provide the skill training that would enable the students to meet them.
- feel pressure not to get involved with innovative teaching approaches, fearing that they will be distracted from their research or that they will be accused of "coddling" or "spoon-feeding" the students.
- may not fully understand or subscribe to the nontraditional instructional methods that characterize the new curriculum, and so may not implement them effectively.
- being human, resist any change from what they are used to.

Assessment-related challenges. Running a clean well-controlled educational study in a natural classroom setting is next to impossible. Student grades, retention, and attitudes depend on hundreds of interrelated factors, many of which are out of the instructor's control, and getting statistically significant results from classroom research studies may require tests on large

populations over a period of years. As a result, assessment and evaluation of such programs often comes down to "We tried it and we liked it and most of the students did too," which has limited convincing power and no scientific validity. Even controlled experiments present considerable challenges, as illustrated in Section VII.

Steep learning curves. Faculty members undertaking new teaching methods normally take several years to become adept at them. However, while professors have several years to develop their teaching skills under normal circumstances, experimental teaching programs are usually evaluated on the basis of their first one or two offerings, while the faculty is still learning how to do them. This fact makes assessment and evaluation that much more difficult.

Heavy resource requirements. The features of innovative educational programs that make them more effective than traditional programs also tend to make them more expensive. The new programs may require smaller classes, more classroom space, renovation of existing classroom space, more faculty contact hours, more teachers, higher teaching loads on current faculty, and/or the purchase of computers, software, specialized audiovisual or experimental equipment, and classroom furniture. Some of the costs are associated with startup, but others require continuing funding.

Lack of administrative support. Department heads and deans may not have educational reform high on their priority list and may not be inclined to support innovative programs unless they can be shown to be less costly than traditional ones. Unfortunately, instructional effectiveness and cost effectiveness are more often contradictory than complementary. Moreover, even administrators who are strong supporters of quality education are plagued by increasingly tight budgets, insufficient classroom space, and shortage of faculty and staff, making them reluctant to provide the resources needed to sustain programs once the funding agency support runs out. They may even find it hard to justify matching funds that may be required during the initial funding period.

Difficulty of transfer. Programs that are highly successful when carried out by the enthusiastic professors who first develop them may not work well (or at all) in the hands of less committed instructors.

Scale-up problems. A small program (in the style of IMPEC) can continue indefinitely if the resources are available. If the program is scaled-up, it is unlikely for the program to continue parallel to a traditional curriculum indefinitely—this causes a division of loyalties and of resources that is not likely to be sustained. Scale-up may therefore have to be total relatively quickly, which is likely to put an intolerable strain on both financial and human resources. This more than any other reason was why IMPEC could not be sustained beyond the pilot test.

IX. Necessary conditions for successful integrated programs

Faculty commitment and skill. An integrated program cannot succeed without

- good teachers who understand and subscribe to the program's philosophy, believe in its

potential benefits, and can sell it to the students.

- good and frequent communication among the participating faculty members. (All the better if they also communicate with colleagues engaged in similar efforts on other campuses.)
- an enthusiastic and highly persistent program coordinator who understands the program philosophy and potential benefits and who can sell the program to administrators and outside funding agencies.
- patience and flexibility from the faculty members, especially during the initial stages of the program.

Suitable training of both students and faculty. In an integrated program, both students and teachers are called on to exercise unfamiliar skills that take time and practice to perfect. To be successful, the program should make provision for

- training of participating students in the study, teamwork, and communication skills needed to succeed in the experimental program.
- training of participating faculty in the specific teaching techniques and skills needed to make the experimental instructional approach work (including the provision of skill training to the students).
- open and frequent communications between faculty and students to detect and correct problems.

A convincing demonstration of program effectiveness. Integrated programs are expensive. An experimental program stands no chance of being institutionalized without

- an assessment and evaluation scheme capable of convincingly demonstrating the effectiveness of the integrated program.
- clear and positive evaluation results.
- either evidence that the demonstrated benefits can be achieved with existing institutional resources or a viable plan to raise the required additional support.

Institutional commitment. Even if the evidence for the effectiveness of an integrated program is indisputable, implementation of the program on even a moderate scale requires

- a university administration (or at least one highly placed administrator) committed to improving undergraduate education.
- administrative commitment to include the program in the regular institutional operating budget to the extent necessary to maintain it.
- incentives for faculty members to participate in the program, or at least the absence of disincentives.

X. Conclusions

In summary, the problems associated with multidisciplinary team-teaching in an integrated program are considerable but far from insurmountable. In our opinion, the ultimate educational benefits to the students more than justify the required effort, and such programs should be

attempted where the conditions for success can be met.

It is certainly clear that, where implementation of an integrated curriculum is not feasible, that there are lessons learned from these experiments. It has been shown that there is benefit in:

- developing cohorts of students, by any means possible. Clustering students into cohorts in their classes, developing learning communities, and establishing mentoring programs are among the ways to do this.
- avoiding early specialization in the engineering curriculum. If the early engineering curriculum is multidisciplinary, students learn better the multidisciplinary nature of engineering and have the time to sort out what they want to major in.
- active and cooperative learning. Regardless of the structure of a curriculum, it is ultimately the pedagogical approach in the classroom that has the greatest impact.

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