First-Year Integrated Curricula: Design Alternatives and Examples*

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ABSTRACT

The National Science Foundation has supported creation of eight engineering education coalitions: ECSEL, Synthesis, Gateway, SUCCEED, Foundation, Greenfield, Academy, and SCCME. One common area of work across the coalitions has been restructuring first-year engineering curricula. Within some of the coalitions, schools have designed and implemented integrated first-year curricula. The purpose of this paper is fourfold: 1) to review the different pilot projects that have been developed; 2) to abstract some design alternatives that can be explored by schools interested in developing an integrated first-year curriculum; 3) to indicate some logistical challenges; and 4) to present brief descriptions of various curricula along with highlights of the assessment results that have been obtained.

I. INTRODUCTION

A long-term key to improving US productivity is engineering education; however, engineering education faces substantial challenges. First, economic factors such as rising costs, reduced operating budgets, aging infrastructure, and increased competition for incoming students from other disciplines are creating pressures for change. Second, the increasing percentage of non-traditional students presents unique challenges for the traditional classroom system, especially for urban universities.[1] Such challenges include balancing class and work schedules, balancing workloads, and traveling between work and university. Third, many studies have documented that traditional classroom teaching may not be the best approach to teach college students.[2–5] These challenges have led to a growing conclusion that a change in teaching pedagogy is needed.

As a result, government, industry, and educational institutions have started searching for innovative ways to improve learning. For example, the National Science Foundation has funded eight coalitions to focus on change in pedagogy and to develop new, high-quality curricula for traditional and non-traditional students in engineering. The eight coalitions are Greenfield, Gateway, ECSEL, Foundation, Academy, SCCEME, SUCCEED, and Synthesis.[6]

This paper summarizes efforts across the NSF-sponsored engineering education coalitions to design, implement and evaluate integrated, first-year curricula. We have explored integrated curricula across the coalitions and abstracted design elements that may be considered by any institution interested in an integrated first-year curriculum. We have examined a large number of issues which have been raised in connection with integrated curricula, synthesized these issues into non-overlapping design options, and described the state-of-the-art regarding these design options for institutions

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interested in future integrated curriculum implementations. The paper explores four broad categories of questions about integrated curricula: motivation, different pedagogical models, logistical issues, and assessment and evaluation processes and results.

II. Motivation: Why Integration?

The following two subsections summarize advantages and disadvantages for integrated curricula.

A. Advantages

Faculty interested in implementing an integrated curriculum must address the question: Why might an integrated curriculum offer an improved learning experience for at least some, if not all, of the entering engineering students? Ten frequently offered reasons are provided below.

1) Learning theory suggests that student learn by constructing their own ideological scaffolding. Students construct, discover, transform, and extend their own knowledge. Learning is something the learner does, not something that is done to a learner. Students do not passively accept knowledge from a teacher or curriculum. They use new information to activate their existing cognitive structures or build new ones. Instructors create environments within which students can construct meaning from new material, study by processing it through existing cognitive structures, and then retain it in long-term memory where it remains open to further processing and possible reconstruction.[7] Integrated curricula deliver such stimulating environments.
2) If an interdisciplinary faculty team designs a comprehensive integrated curriculum, then they can avoid haphazard repetition of material and focus on concepts that students have trouble learning. Class time is saved with one-time introductions on common topics such as team skills, computer tools, vectors, and units. These common topics may be introduced once, then applied and reinforced later. Also, careful design will allow instructors to reinforce difficult topics by knowing what their colleagues have presented. Students can then see several instructors presenting similar topics and each presentation could appeal to different learning preferences.
3) Re-arranging topics so students learn related concepts simultaneously promotes a broader-based level of understanding rather than a more narrow discipline-specific understanding of each topic.[8]
4) If instructors do not provide a proper framework, then students will have enormous difficulty assimilating new information. If instructors link current material to other concepts that students are currently learning, then the probability that students will assimilate the material is increased, since the number of nodes in a student's conceptual framework to which the new material may be linked is increased. The result is better retention of material.
5) Since integrated curricula decrease compartmentalization, they align better with the practice of engineering. Engineering problems do not typically occur in discipline-oriented categories. Instead, engineers solve real-world engineering problems by synthesizing knowledge across several different disciplines.[9,10] Further, since integrated curricula help students to visualize and understand links among different disciplines, these links can help them synthesize multi-disciplinary solutions.
6) Integrated curricula can help smooth transition between subjects. For example, laboratory experiments in physics, chemistry and engineering can be designed to reinforce common concepts.[11] It may also be possible to develop a common report format that is used across the curriculum.
7) Integrated curricula help to establish relevance between the material being studied and student perception of their career needs. As a result, students are more highly motivated to master material being presented.
8) Integrated curricula, with teams of instructors and emphasis on links between subjects, offer more opportunities to connect with the range of student learning preferences.
9) Integrated curricula often develop student abilities to work in teams. Instructors serve as role models so students can learn from watching instructors function as a team.
10) Instructors who teach on an interdisciplinary team are better informed about the overall curriculum.

B. Disadvantages

In contrast, five reasons are often cited for not implementing integrated curricula.

1) "We can't do that. Although some schools have implemented integrated curricula, the needs of our students and our institutional culture prevent offering an integrated curricula at this institution."
2) "My class is five hours per week and I need all of the time allocated." Instructors don't believe there is sufficient time to allow presentations and activities to be coordinated.
3) "I can't work with instructors from other departments." "I have to cover the material my way." Instructors often express reluctance to work in teams with other faculty, especially across departmental boundaries. Instructors who are accustomed to working alone may resist initiatives that could change their preferred mode of operation.
4) "I believe students have to pass everything at the same time for integrated curricula to be successful." "Students come with different backgrounds. Our current mode works well for ultimate flexibility." One the major obstacles to implementing integrated curricula are tradeoffs between the breadth of integration and the flexibility of curricula to accommodate different student needs. When a large set of courses are integrated into a single curriculum, the number of students who can participate in the integrated curriculum may be too small.
5) "We will give students the topics, let them do the integration." Some faculty believe it is the responsibility of students to make connections among the topics they are studying. They do not believe it is appropriate for faculty to help students identify and process these connections.

III. Pedagogical Models: One Size Does Not Fit All

Although certain benefits from curriculum integration can be realized at every institution, one approach to first-year integrated curricula will not work for all institutions. Differences in mission, student population, and institutional culture demand different models. This section will explore different models that have been implemented at different schools across all the coalitions.

The Engineering Education Coalitions have tried numerous integrated curriculum models. Rather than describe all of the variations that have been tried, a multi-dimensional framework is presented into which both existing and future experiments may fit. The framework has five dimensions: course structure, time-sharing, topical span, topical coordination, and learning environment.

A. Course Structure

The first dimension is course structure. Along this dimension are three distinct options and variations within each option.

- Separate courses: Course structure is the same as for a traditional set of courses taken by any first-year engineering students. In this option, courses such as calculus, physics and chemistry retain their independent departmental structure and integration is achieved primarily through topical alignment.
- Course pairs/triads: Two or three first-year courses are linked together so that students jointly registered for the set. Students may receive separate credit for each of the linked courses or block credit for the set. The course pair/triad option may provide flexibility for institutions such as community colleges or large urban universities that serve a large percentage of non-traditional students.
- Large course block: Students take a large block of courses, for example, calculus, physics, engineering, writing/communication, and chemistry, simultaneously. They may receive separate grades for courses in the block or they may receive a single grade for the entire course block.

B. Time-Sharing

Time-sharing describes how instructors allocate time to each of the courses in the integrated curriculum. Two major variations exist: dynamic allocation and static allocation.

- Dynamic allocation: Instructors routinely adjust time shared among courses throughout the term (quarter or semester). Under dynamic allocation, the team may allot mathematics more time during one week to work on difficulty concepts or develop mastery with certain skills, such as a computer algebra system. Mathematics receives a reduced allocation in the following weeks.
- Static allocation: Instructors allocate a fixed amount of time each week to each course. Static allocation usually follows traditional course allocation methods. For example, mathematics may receive four hours per week and chemistry three hours per week for the entire term.

Dynamic allocation offers flexibility in scheduling topics so that links can be emphasized on a daily basis and students can focus on specific, difficult concepts for a longer period. However, dynamics allocation requires a higher level of coordination among the interdisciplinary team while fixed-time allocation requires less adaptation for participating instructors.

C. Topical Span

Topical span describes the range of courses that are being integrated. Again, numerous combinations have been tried both across the coalitions and beyond the coalitions. Two major variations should be mentioned. In the first, only courses from mathematics, science, and engineering are integrated. In the second, courses from mathematics, science and/or engineering are integrated with courses in non-technical areas such as writing, communication, team dynamics, and others. Within both variations, a number of combinations have been tried: a) mathematics and a physical science such as physics or chemistry, b) science and engineering, c) mathematics and engineering, d) material science and chemistry, or e) engineering and communication.

D. Topical Coordination

Topical coordination describes mechanisms that help students build links among topics. Mechanisms include nomenclature coordination, topical reorganization, integrated examinations, and projects.

- Nomenclature coordination: Instructors establish and use a common nomenclature and set of symbols throughout the curriculum. Instructors recognize that different disciplines use different terminology, symbols, and units. They point out where different terms, symbols, and units are used and how they are related.
- Topical reorganization: Instructors reorganize the topics in the integrated structure to help create links and ensure common foundation information and prerequisite material.
- Integrated examinations: Instructors may use a single exam with integrated problems to test the student over all subjects, or discipline-specific exams where the student is expected to apply knowledge from other integrated topics. Numerous variations have been tried.
- Integrated design projects: Projects can help students synthesize concepts from several different disciplines and demonstrate the relevance of these concepts to engineering practice.

E. Learning Environment

Integrated curricula instructors have varied many different aspects of the learning environments. Reference 12 provides more detailed descriptions of the alternatives that have been tried across the coalitions. Section VI describes specific changes in learning environments that have been tested in integrated curricula at different schools.

IV. IMPLEMENTATION/LOGISTICS ISSUES

Interested instructors have raised numerous questions about implementation of an integrated curriculum. This section attempts to raise as many issues as possible. Each integrated curriculum has overcome these challenges in unique ways. For details, consult the references for a particular institution.

- Course scheduling: Difficulties include working across departmental lines and problems in linking courses for cohort registration.
- Classroom scheduling: Classroom space is always a problem. Additional issues include technology needs for an integrated course, laboratory space needs, and scale-up problems of the increased number of sections needing active learning classrooms.
- Grade assignment, reporting and recording: Non-traditional credit assignments, e.g., twelve-credit courses, four-credit

courses taken one credit per term, pose difficulties for the registrar.

- Accounting of credits: Among the biggest obstacles to integration are the accounting boundaries between academic units, for example, college and department credit for faculty loads, that exist at many campuses.
- Different entry points: Integrated courses can create problems for students that transfer, students with advanced placement credit, and students with inadequate preparedness. Methods that addressed these issues include a pre-calculus track, extensive mathematics diagnostics coupled with pre-calculus instructional modules, and one-credit courses.
- Substandard performance: Students who perform poorly require innovative solutions that allow them to continue to progress in an integrated curriculum.
- Faculty development: Integrated curricula usually require the faculty to operate in a different type of learning environment. Many use learning environments that reduce lecture and increase faculty mentoring (see the preceding section). Engineering faculty generally have not formally studied pedagogy. Consequently, integrated curricula require a well-planned faculty development component if they are to succeed. Questions that must be addressed include: How do faculty learn to participate on interdisciplinary teams? How do faculty learn about areas outside their areas of expertise? How do faculty learn to incorporate computer technology into their teaching and into student learning? How do faculty learn to form and facilitate student teams?

V. Assessment Measures and Processes

Two very broad questions should be addressed. First, how do you determine if the integrated curricula experiments offer a superior learning environment? Second, what assessment results have been obtained from the various integrated curricula experiments? The first question will be addressed next. The second question will be addressed in section VI.

Institutions have attempted to measure success of integrated curriculum pilots in a number of ways. The most common are though retention studies, grade point average (GPA) performance, and student self-evaluation. Retention can mean many things and four types of retention measures have been frequently employed.

1) Retention within the curriculum: What percentage of students who were initially enrolled in the integrated curriculum completed the program?
2) Retention within engineering: What percentage of students who were initially enrolled in the integrated curriculum is either still enrolled in the college of engineering or has graduated with a degree in engineering?
3) Retention within the institution: What percentage of students who were initially enrolled in the integrated curriculum is either still enrolled in the institution or has graduated?
4) On-track performance: What percentage of students who were initially enrolled in the integrated curriculum is projected to complete their degree within four years?

All four measures are important, especially to different stakeholders within the institution, but each measures a different aspect of the program's effectiveness. Issues connected with GPA performance are more complicated.

1) To what extent is the GPA of students in the integrated curriculum important?
2) To what extent is the GPA after the first-year of the students who complete an integrated curriculum important?

Student self evaluation is important, but the results may be difficult to interpret. The variety of measures of success, the variety of methods through which the measures of success have been implemented, and the wide variety of types of schools who have piloted integrated curricula make interpretation of the results very complex.

Other assessment measures that have been used are 1) end of term class assessment by students, 2) end of term teacher assessment by students, 3) self and team member assessment of student teamwork skills, 4) weekly anonymous journals—open or selected topics, 5) student interviews—students leaving programs—students staying in programs, 6) overall GPA, 7) progress toward graduation, 8) surveys of industry for input (alumni and managers), 9) rating by students of opportunities to work on ABET competencies, 10) faculty interviews, 11) longitudinal tracking of retention, 12) specific GPA for a course sequence, 13) co-op/internship participation, 14) University of Pittsburgh survey of student attitude toward engineering.[13]

Finally, evaluation of effectiveness requires comparison of the students with students in a comparison group. The following are three issues that must be considered when reaching conclusions regarding the effectiveness of an integrated curriculum.

1) To which group is the performance of students who complete an integrated curriculum compared? Is it possible to obtain a reasonable comparison group?
2) How is the comparison group selected? What criteria are used?
3) Are faculty external to the integrated curriculum involved in the design of the analysis of student performance?

The critical issue is what is the desired objective of the integrated curriculum. In many cases, the objective is improved content understanding. This is much more difficult to measure and has been measured to a much more limited extent.

VI. Coalition Survey—Unique Characteristics, Assessment Results

Several integrated curriculum experiments will be reported here. A summary of the different programs is included in table 1.

In the following sections, each curriculum will be described briefly along the dimensions outlined in the section on different pedagogical models. Special variations of the pedagogical model can be noted along with exceptional solutions to the logistical issues outlined in section three. Finally, selected assessment results will be shared for each experiment. Readers interested in more complete descriptions of the assessment results are referred to the references.

A. Rose-Hulman Institute of Technology

Rose-Hulman Institute of Technology has offered an Integrated, First-Year Curriculum in Science, Engineering and mathematics (IFYCSEM) since 1990.

Innovations: IFYCSEM has pioneered at least five significant innovations.

Program	Ref.	Course Structure	Time Sharing	Topical Span	Topical Coordination	Learning Environment
IFYCSEM (Rose-Hulman)	[14-25]	large course block, one 12-credit grade	dynamic allocation	calculus, physics, computer science, engineering, chemistry	topical alignment, integrated exams	cooperative learning, teams, team projects, required notebook computers
University of Florida	[26]	separate courses	static allocation	calculus, physics, chemistry, engineering	pre-arranged topical alignment	cooperative learning, teams, student cohorts, computers in classroom
FYIEC (Texas A&M University - Kingsville)	[10, 27, 28]	large course block with separate grades	90% static allocation, 10% dynamic allocation	mathematics, physics, chemistry, engineering, and English	topical alignment, thematic concepts, integrated exams, integrated design projects.	co-op learning, teams, team projects, computers in classroom, student cohorts
Ohio State University		course triad	static allocation	calculus and diff. eq., engineering, physics, statics, technical writing	nomenclature coordination, some topical alignment	cooperative learning, Computer-Aided Instructional (CAI) materials, computer tools introduced once
Texas A&M University	[29-37]	large course block, separate grades	static allocation	calculus, physics, engineering, chemistry, calculus and physics are more tightly coupled	nomenclature coordination, topical alignment, integrated exams, integrated projects	active/cooperative learning, student teams, team exams, student cohorts, student-faculty interaction groups
IMPEC (North Carolina State University)	[38-41]	large course block, separate grades	¾ static allocation and ¼ dynamic allocation	mathematics, science, and engineering, with written and oral communication	integrated lectures, homework assignments, projects, and examinations	structured cooperative learning, experiential learning, teams
Arizona State University	[42-50]	large course block, separate grades	dynamic allocation	mathematics, physics, and engineering, English	integrated lectures, homework assignments, projects, and examinations	structured cooperative learning, experiential learning, teams
TIDE (University of Alabama)	[51-67]	large course block, separate grades	dynamic allocation	mathematics, physics, chemistry, and engineering	integrated lectures, homework assignments, projects, and examinations	structured cooperative learning, experiential learning, teams
Greenfield Coalition	[68-70]	one credit course modules	static allocation	mathematics, physics, engineering	nomenclature coordination, topical alignment	computer-based instruction, experiential learning
Maricopa Community College District		course pairs	static allocation			
Drexel University	[71-78]	large course block, separate grades	static allocation	mathematics, physics, biology, chemistry, engineering, and humanities	homework assignments, faculty team meetings	experiential learning, teams

Note: Every pilot project includes mechanisms for student feedback so this aspect is omitted from the learning environment.

Table 1. Summary of integrated first-year curriculum experiments.

1) An interdisciplinary faculty team has developed and revised a yearlong curriculum that successfully integrates concepts across calculus, mechanics, engineering statics, electricity and magnetism, general chemistry, computer science, engineering design, and engineering graphics.
2) IFYCSEM has developed a positive and flexible learning environment that emphasizes continuous improvement through student-faculty interaction and assessment. Student-faculty interaction is facilitated by interaction between the faculty team and student cohort, an elected IFYCSEM council that meets bi-weekly with faculty, and plus/delta feedback.
3) IFYCSEM has developed a collaborative learning environment through cooperative learning, team training, team projects, sophomore mentors and base teams (teams which

exist throughout the entire quarter for learning as well as support).
4) IFYCSEM has helped faculty and students integrate and unify concepts across disciplines.
5) IFYCSEM has helped pioneer learning environments in which students have routine access to computer workstations and software.

Assessment: The IFYCSEM summative evaluation model uses both quantitative and qualitative methods. Baseline data is collected from all RHIT students prior to the beginning of the first year. Data that include scores on critical thinking skills,[22] intellectual development, Force Concept Inventory,[79] Mechanics Baseline Test,[80] and personality type preferences[22] provide a rich baseline for examining program outcomes. Evaluation includes post-testing on baseline measures, retention at Rose-Hulman, grades in upper-level courses, faculty assessment of student characteristics in upper-level courses, and student focus groups.

Students volunteer to participate in IFYCSEM. IFYCSEM student performance is assessed relative to a comparison group who takes the traditional curriculum. Cluster analysis is used to match students from the traditional curriculum with IFYCSEM students using characteristics such as predicted grade point average, SAT scores, pre-test scores on baseline assessment measures and parents' education. These two groups have been tracked through their upper level courses and their performances compared. Comparison data include grades, persistence at Rose-Hulman, faculty assessment of student characteristics, and post-testing at the sophomore and senior levels.

Overall, summative assessment data show that students who complete the IFYCSEM program do significantly better than the students in the matched comparison group both in persistence at Rose-Hulman and grade point average in upper-level courses. All these differences with respect to the carefully constructed matched comparison group are statistically significant. As upper class students, they were rated more highly by faculty in the areas of their communication skills, ability to integrate the use of technology for problem solving, ability to develop their ideas to appropriate conclusions, and ability to integrate previous knowledge into their current work. Retention and grade point average data for both students who completed IFYCSEM and carefully matched comparison groups are shown in table 2. Data on the faculty evaluation of sophomore students can be found in.[24]

Evaluation of new curricular initiatives is difficult because carefully controlled experiments can not be conducted. Despite a well-designed assessment plan and extensive data collection, students, faculty and staff at Rose-Hulman do not agree on a single set of conclusions. The following points are intended to represent a spectrum of conclusions.

1) The question of whether IFYCSEM offers a superior learning environment to the traditional curriculum remains open. The central issue is whether conclusions drawn from the assessment results using two groups, students who completed IFYCSEM and the matched comparison group, can be extrapolated to the entire entering student body.
2) Students who complete IFYCSEM earn forty-one credits. Therefore, IFYCSEM covers the equivalent of forty-one credits of material in a thirty-six credit format.
3) There is universal agreement that students who have participated in IFYCSEM have not, on the average, been hindered in their subsequent academic careers.

B. University of Florida

In 1994, the SUCCEED Coalition supported an integrated freshman-sophomore curriculum experiment. The project ran for two years with a cohort of 92 students. The main objectives were to: 1) provide a more structured academic and social learning environment; 2) provide applications and introduce the engineering thought process in the first two years; 3) search for models that are sustainable, cost effective and transportable; 4) match teaching and learning styles (e.g., cognitive and active learning); and 5) develop an advanced learning laboratory to provide optimal physical facilities.

Faculty made the following course modifications as part of the experiment.

1) Calculus was converted from three lecture hours and one recitation per week to three lecture hours, one 2-hour problem laboratory and one 1-hour recitation per week.
2) Physics was converted from three lecture hours and one companion laboratory class per week to two lecture hours, one 2-hour problem laboratory, and one companion laboratory class per week.
3) Chemistry lecture format was maintained, but the laboratory portion of the class was converted to a data-acquisition based, group laboratory format.

The following results illustrate the impact of the changes on student learning. Characteristics of the integrated curriculum cohort and the matched comparison group may be found in.[12] Retention results are based on students who stayed in engineering at the end of the two-year experiment as compared to a control group that entered at the same time. Students who participated in the program were retained at a higher rate than students in the comparison group. Retention results and overall GPA data for the first two years of mathematics are shown in table 3.

	Entering Cohort	1990	1991	1992	1993	1994	1995	1996
Retention after IFYCSEM Completion	IFYCSEM	89.7%	92.8%	98.2%	81.4%	93.2%	92.9%	94.3%
	Comparison	71.8%	84.1%	73.2%	64.4%	89.8%	91.8%	98.9%
Sophomore Fall Quarter GPA	IFYCSEM	3.349	3.166	3.227	2.966	3.029	2.969	2.847
	Comparison	2.798	2.700	2.571	2.576	2.675	2.640	2.650
	All Students	2.765	2.736	2.628	2.736	2.688	2.807	2.740
Junior Fall Quarter GPA	IFYCSEM	3.423	3.022	3.254	2.988	3.275	3.099	
	Comparison	2.867	2.805	2.830	2.873	3.036	2.925	
	All Students	2.868	2.834	2.929	2.903	3.020	2.964	
Senior Fall Quarter GPA	IFYCSEM	3.415	3.256	3.275	3.082	3.173		
	Comparison	2.951	2.970	2.928	2.963	2.973		
	All Students	3.028	3.088	3.088	3.079	2.996		

Table 2. Post-IFYCSEM student performance assessment—Rose-Hulman.

		Program Students	Comparison Group
Retention Data	Started Program	92	571
	Completed (enrolled for Junior year)	55	286
	Percent	60%	50%
GPA in the First Two Years of Math	Number of Students	55	275
	GPA for all mathematics course	3.03	2.88

Table 3. Student performance assessment—University of Florida.

Year	FYIEC	Traditional
1995	58 % (26)	56 % (25)
	2.5 GPA	2.37 GPA
1996	63 % (24)	46 % (26)
	2.75 GPA	2.29 GPA

Number in parenthesis denotes total number of students in each group.

Table 4. Retention and GPA of FYIEC and matched comparison groups—TAMUK.

			Math	Sci.	Eng.
Earned Credits After First Year	1995	FYIEC	5	9.2	5.2
		Traditional	3.2	4.2	1.7
	1996	FYIEC	6	11.2	4.7
		Traditional	3.3	4.7	3.3

Table 5. Progress towards degree of FYIEC and matched comparison groups—TAMUK.

None of these results were statistically significant, possibly due to the small number of project students. The trends are encouraging, and data are being analyzed further.

C. Texas A&M University—Kingsville

As a partner in the Foundation Coalition, Texas A&M University—Kingsville (TAMUK) has offered its First-Year Integrated Engineering Curriculum (FYIEC) since fall 1995. As indicated in table 4, in a two-year span, retention and GPA of FYIEC students is better, particularly in 1996, relative to matched compared groups of traditional first year engineering students. In addition, in both years, FYIEC students outperformed traditional students in the number of math, science, and engineering credits earned in their first year. These results, shown in table 5, indicate they are progressing faster towards graduation.

D. Ohio State University

Since 1993, Ohio State has offered an integrated first-year curriculum with the characteristics shown in table 1. During these five years, 381 students have participated in the curriculum. Participants were honors students who volunteered for the four pilots. Faculty made the following course modifications as part of the experiment.

1) Physics instructors use active and cooperative learning.[81] Special labs are set up for the first Physics course using Hot Wheels cars and the students must design the experiments to determine forces, displacements, velocities and acceleration. Two nationally normed tests (Mechanics Baseline Test and Force Concepts Inventory) are used as part of the course assessment. The 1997–98 Ohio State students outperformed all other groups on one test and all but one on the second test. Instructors coordinate topics in physics, mathematics, and statics so they are covered just in time.
2) Physics and engineering instructors have developed and used Computer-Aided Instructional (CAI) materials.
3) Instructors have created a hands-on laboratory for students in the curriculum. They use laboratory experiments as a basis for experiential (discovery, problem-based) learning.
4) Engineering instructors use teams for laboratory experiments and design projects.
5) Engineering instructors teach statics using CAI materials to augment lectures.
6) Students send anonymous, weekly journals to a group of faculty and staff. These journals are discussed in weekly faculty meetings.
7) Students assess themselves and each other for team learning and laboratory exercises.
8) Instructors have aligned the program objectives with ABET 2000. They are working on course objective alignment.
9) Instructors have placed computers in the engineering classroom and made computers available in laboratory for freshmen engineering students. Instructors introduce computer tools once, then they use them more than once in other courses.
10) In the spring quarter, the students work in four-person teams where each team designs and builds and autonomous robot for an end-of-the-quarter competition. Students use Physics, Mathematics and Engineering (graphics, computer programming) topics and hands-on laboratory experiments during the projects. Physics, Mathematics and Engineering faculty, and graduate teaching associates choose teams.

To evaluate the impact on student learning, Ohio State has tracked retention, GPA, GPA in follow-on mathematics and physics courses, and participation in co-op/internship. In brief, retention is 10% higher than matched comparison groups if students complete one quarter, more than 20% higher if they complete the year. Overall GPA is higher by junior year. Participation in co-op/internships is higher.

E. Texas A&M University

Faculty at Texas A&M University (A&M) have redesigned the first-year curriculum to nurture development of the following attributes in their graduates: 1) good grasp of engineering science fundamentals; 2) profound understanding of the importance of teamwork; 3) curiosity and desire to learn for life; and 4) good communication skills. The engineering component of the curriculum has the following central goals: 1) provide students with necessary skills to perform effective problem solving; 2) help students develop logical thought processes; 3) introduce students to basic engineering tools; 4) enable students to have better spatial analysis skills; 5) help students develop appropriate sketching skills; 6) teach students how to read and/or interpret technical presentations; and 7) develop the ability to think both critically and creatively—independently and cooperatively.

Course Structure: Since the fall of 1994, 775 students have registered in the Foundation Coalition pilot first-year engineering program. Of these, 633 participated in the calculus track described herein. The remaining 141 have participated in a pre-calculus track that resembles the calculus track—delayed by one semester. The freshman year of the Foundation Coalition program at A&M consists of a large course block including: a semester of chemistry (4 hours of chemistry including lab), a two semester English writing class (3 hours of English, technical writing follows in the sophomore year), a two semester engineering course (5 hours of engineering including engineering graphics, and an introduction to engineering problem solving and computing), two semesters of calculus (8 hours of mathematics although not all material comes from the first two semesters of a traditional calculus class), and two semesters of physics (7 hours of physics including mechanics, and electricity and magnetism). The courses are delivered to students as a 12-hour block in the fall semester and a 15-hour block in the spring semester. Separate courses grades are given within the blocks. These are taught in an integrated, *just-in-time* fashion using technology and delivered in an active-collaborative environment to students working in teams of four.

Time Sharing: Each course is taught in a standard university time block (static allocation). However, each instructor occasionally gives up a class period for common topics such as team training, team development, or a speaker from industry. In addition, there is an understanding that small amounts of time can be traded or given to colleagues in other courses to improve the flow of the course block.

Assessment: Overall, A&M has been successful in both recruitment into the pilot curriculum and retention in the College of Engineering (number at the start of their third semester as a percentage of those starting the first semester). Students in the pilot curriculum are retained at a rate higher than the rate for those in the traditional freshman program. This is especially true of students from underrepresented groups: women, Hispanic, and African-American engineering students. Selected recruitment and retention statistics for underrepresented students in the college of engineering and in the pilot curriculum are presented in tables 6 and 7 (others years are available).

Grade point averages for the coalition students and those students completing the same courses in the traditional program are essentially the same. On the other hand, as illustrated below, the distribution of grades is not the same (table 8 below represents those students who do *not* successfully complete the courses).

	Women	Hispanic	African-American
All Engineering	19.8%	11.0%	3.2%
Math Ready	19.8%	10.3%	1.7%
Coalition	24%	16%	5%

Table 6. Enrollment by gender and ethnicity (1995–96 freshmen)—A&M.

	Women	Hispanic	African-American
Traditional	72%	70%	70%
Coalition	88%	84%	90%

Table 7. Retention by gender and ethnicity (1995–96 freshmen)—A&M.

	English	Engin.	Math	Physics
Traditional	17.17%	19.84%	33.75%	43.08%
Coalition	6.52%	16.09%	12.57%	17.9%

Table 8. Percentage of D, F and Q-drops—A&M.

Students with grades of D, F, or Q (quit before end of tenth week of class) represent those students who will be repeating the course, and therefore requiring greater resources. It should be noted that the difference between the percentages in table 8 is due to Q-drops. Students in the integrated pilot curriculum are not allowed to Q-drop a course because of integration among courses.

A series of standardized tests, including a critical thinking test (SCT), the Force Concepts Inventory (FCI),[79] a Mechanics Baseline Test (MBT),[80] and a Calculus Concepts Test (CC),[31] has been administered to the students in the freshman coalition classes and to a similar group of students in the traditional freshman engineering classes each year. Although performances by the two groups are virtually identical when the instruments are administered at the start of the year, table 9 shows that there are substantial differences between the two groups when the instruments are administered again at the end of the year. Finally, results from the Gregorc Style Delineator[32] can be found in reference [12].

F. Greenfield Coalition

The Greenfield Coalition challenge is to develop and deliver a new paradigm manufacturing education in both engineering and engineering technology. The central features of that paradigm are intimate blending of academic and experiential learning, use of modularized and integrated learning experiences, and use of advanced instructional and information technologies. Greenfield curricula offer learning to candidates who want to become manufacturing engineers or engineering technologists. They are a combination of students and key employees in an advanced technology factory. Therefore, the Greenfield Curriculum Committee devised a high-level design for integrating the fundamental content of conventional physics courses with their application in relevant engineering sciences.

The curriculum serves candidates in three degree programs (AS, BE and BET). This presents unique challenges that have been addressed throughout the project (planning, developing, and delivery). The curriculum provides five credit hours. Three credit hours are common for all degrees (AS, BE and BET), one credit hour for engineering and engineering technology (BE and BET) students, and one credit for engineering (BE) students only.

In the Greenfield curricula, concepts in physical science are introduced and immediately followed by their extensions in engineering sciences. For example, curricula include real-world case studies, particularly from Focus:HOPE's Center for Advanced Technology (CAT). Courseware reinforces intimate blending of fundamental theory and practical application in the context of manufacturing

	Critical Thinking	Force Concept Inventory	Mechanics Baseline Test	Calculus Concept Test
Traditional	41	51.2	37	47
Coalition	57	66	47	57

Table 9. Performance on standardized tests—A&M.

engineering and technology. This contextual relevance is central to the development of the "integrated engineering science" knowledge areas.

Greenfield re-examined engineering fundamentals and revised the material to emphasize links to manufacturing practice while preserving academic rigor. Instructors reorganized material in physics and engineering science into three "stems": mechanophysics, electrophysics, and thermophysics. The mechanophysics curriculum is described in reference [68], the thermophysics curriculum is described in reference [69], and the electrophysics curriculum is described in reference [70].

Instructors reinforce integration across the three stems using topical coordination techniques: 1) use of a common glossary and nomenclature; 2) use of a common interface to minimize redundancy and reduce ambiguity, and 3) use of a common sequencing of activities that should not constrain the possibility of adding new activities where considered appropriate and effective.

Finally, the last and most difficult challenge is to develop the curriculum in which computer-based instruction (CBI) is the main source of instruction for candidates. There have been few developments in this area, most of which have been intended as supplements or tutorials. The objective of this project is to develop a CBI curriculum, which includes real-world case studies, as the main source of instruction for candidates.

G. IMPEC (North Carolina State University)

An integrated freshman engineering curriculum called IMPEC (Integrated Mathematics, Physics, Engineering, and Chemistry Curriculum) has undergone three years of pilot-testing at North Carolina State University under the sponsorship of the SUCCEED Coalition. In each semester of IMPEC, the students take a calculus course, a science course (chemistry in the first semester, physics in the second), and a one-credit engineering course. The engineering course has a heavy dose of non-technical skill training, with the skills including written and oral communications (report writing, presentation graphics), teamwork skills, and time management. The curriculum is taught by a multidisciplinary team of instructors using a combination of traditional lecturing and alternative instructional methods including cooperative learning,[81] activity-based class sessions, and extensive use of computer simulations. The goals of the curriculum are to provide: 1) motivation and context for the first-year mathematics and science material; 2) a realistic and positive orientation to the engineering profession, and 3) training in the problem-solving, study, and communication skills that correlate with success in engineering school and equip individuals to be life-long learners.

Instructors made the following course modifications.

1) Instructors integrate lectures, homework assignments, projects, and examinations.
2) Instructors used structured cooperative learning, with several mechanisms in place to provide both positive interdependence and individual accountability.
3) Chemistry and physics instructors made extensive use of experiential (discovery, problem-based) learning.
4) Instructors assigned two computers for every three students in the classroom. Students used Microsoft Word, Microsoft Excel, Maple, and Microsoft PowerPoint.
5) Students completed midterm and final evaluations, and the teams regularly submitted self-assessments on how they were functioning—what they were doing well and what they needed to improve.
6) Student teams stayed together for the entire semester working on in-class work, weekly homework, and semester projects. In the opinion of the instructors, students think that the team structure is the strongest feature of the curriculum.

Interested instructors have raised numerous questions about implementation of IMPEC.

- Course scheduling—IMPEC was assigned dedicated sections of regularly scheduled courses, and block-scheduled the students into them. One of the faculty members did this sort of thing for his department and so knew how the system handled the arrangements.
- Classroom scheduling—IMPEC shared a specially equipped classroom usually allocated to the Electrical and Computer Engineering Department.
- Grade assignment, reporting, and recording—IMPEC handled these tasks like regular courses. The integrated exam grades were counted in whichever courses were being integrated.
- College and department credit for faculty loads—A SUCCEED grant has provided release time to the participating faculty and the faculty members themselves received some summer salary. Development time will be a significant challenge when external funding goes away. NCSU instructors have concluded that the full level of integration we achieved in the pilot study will be impossible to scale up at a research university.
- Different entry points—Instructors addressed this issue by admitting only students who were eligible to take the courses. This excluded both students with AP credit for any of the courses and students who didn't qualify for them. Again, this is a significant challenge when scaling up the curriculum.
- Students who perform poorly—The few who failed any of the IMPEC courses were required to drop back into the regular curriculum.
- Faculty development—Faculty learned to participate on interdisciplinary teams by doing it and growing from the experience. It would have been much easier if at least one faculty member had prior experience. Faculty learned to form and facilitate student teams by working on faculty teams that included someone who had the requisite knowledge and that willingness and ability to teach it to others. Another alternative would be short topical workshops.

Retention, GPA data, on-track performance, performance on common examinations and examination questions, performance on standardized tests, attitudes and confidence levels for both students who completed IMPEC and matched comparison groups were used as assessment measures. The IMPEC students outperformed the comparison students on virtually every measure, with many of the differences being highly statistically significant. Details are given in reference [41].

H. University of Alabama

Description: The University of Alabama began offering their integrated freshman curriculum (TIDE—Teaming, Integration, and Design in Engineering) in the Fall of 1994. The initial pilot involved two semesters of integrated courses in chemistry, engineering, calculus, and physics. The TIDE mathematics courses differed a great deal from the traditional approach in that the TIDE courses used computer-based algebra systems. There was also considerable rearrangement and deletion of material. The TIDE curriculum replaced the traditional graphics and programming courses with new courses, Foundations of Engineering I/ II. These courses introduced students to the fundamentals of engineering design, computer-based problem solving (both productivity tools and programming languages), and teaming. The engineering design projects and in-class problem solving exercises integrated concepts from chemistry, math, and physics and motivated the students with regard to the importance of these fundamentals.

Assessment: Assessment results of the first offering indicate that the TIDE students had a higher rate of retention within the College of Engineering (see table 11), higher cumulative GPAs (2.427 vs. 2.186), a greater number of attempts in the second calculus course, (61% vs. 28%) and higher GPAs in the second calculus course (2.116 vs. 1.834) than a comparison group. Table 10 shows retention within the College of Engineering of the cohort of students who participated in TIDE in the Fall of 1994 compared to a comparison group of calculus-ready first-year students and the entire class of first-year students. Table 11 shows the same data for the cohort of students who participated in the TIDE in the Fall of 1995. A pre-calculus track was added in 1996 in order to make TIDE available to more students at the University of Alabama. Data has been gathered for both tracks since the pilot began and results have been very encouraging. In fact, the assessment results were a strong contributing factor to the recent recommendation by a faculty committee that the FC curriculum replace the traditional beginning in 1999.

I. The Drexel Engineering Curriculum

History: In 1989, Drexel University initiated a major curricular change entitled "Enhanced Educational Experience for Engineers" or simply E^4. Supported by the National Science Foundation, the GE Foundation, the Ben Franklin Partnership, and several major U.S. corporations, Drexel faculty designed, developed, and tested a new freshman and sophomore engineering core curriculum emphasizing: 1) interdisciplinary scientific foundations integrated with engineering applications; 2) laboratory oriented experiential learning; 3) extensive utilization of the computer to enhance learning; 4) development of communications and effective teamwork skills; 5) design as an integral part of the professional practice; and 6) the culture of life-long learning.

In 1989, 1990, and 1991, cohorts of 100 students entered the experimental E^4 program. The students entering the E^4 program were randomly selected from volunteers having generally similar levels of academic preparation and achievement as the non-E^4 cohorts. The success of the program resulted in the expansion of the E^4 program to two cohorts of 100 freshman students in the fall of 1992. The College of Engineering simultaneously began to examine the extension of the curricular revision to all five years with the first two years based on the E^4 experience. In 1993, an analysis was performed on the retention rates, GPA, and completion to degree. These results clearly showed the positive effects of the new curriculum on student performance and success rate. In early 1994, the Faculty Senate unanimously approved the new Drexel Engineering Curriculum. In the fall of 1994, all 500+ engineering freshman were admitted to the new program. In fall 1995 the program was evaluated by ABET and received full accreditation.

In early 1992, NSF funded the Gateway Engineering Education Coalition consisting of ten universities under Drexel's leadership for

	Foundation Coalition Cohort: N=36	Calculus Ready Comparison Group: N=86	All F94 COE Freshmen: N=309
Fall 94	100%	100%	100%
Spring 95	100%	92%	86%
Fall 95	86%	77%	69%
Spring 96	81%	66%	58%
Fall 96	78%	59%	49%
Spring 97	72%	57%	44%

Table 10. Retention within engineering, University of Alabama, Fall 94 cohort.

	Foundation Coalition Cohort: N=61	Calculus Ready Comparison Group: N=69	All F95 COE Freshmen: N=324
Fall 95	100%	100%	100%
Spring 96	98%	96%	85%
Fall 96	92%	74%	67%
Spring 97	85%	70%	56%

Table 11. Retention within engineering, University of Alabama, Fall 95 cohort.

a five-year duration. Two of the key objectives of Gateway were to share E[4] innovations with the other coalition members, and to build new upper division curricula (i.e., beyond the sophomore year) on this foundation. Drexel has concentrated on sharing and disseminating E[4] innovations within Gateway, and has completely restructured its five-year co-op-engineering program for all engineering majors. The June 1999 graduates were the first to complete all five years of the new curricula.

Description: The core of the Freshman Engineering program is built on two themes: curricular integration and engineering design and laboratory. Typical freshmen take Mathematical Foundations of Engineering (MFE), Physical Foundations of Engineering (PFE), Chemical & Biological Foundations of Engineering (CBFE), Engineering Design & Laboratory (ED&L) and Humanities. In the three yearlong courses, MFE, PFE and CBFE, topics of mathematics, physics, chemistry, and biology are presented from an application and engineering perspective. Humanities instructors coordinate the content of the course with all other course instructors. For a more complete description of the curriculum, see references [71–78].

Assessment: E[4] established a dramatically different approach to the engineering educational process than the traditional programs that were widespread and dominant for over the last forty years. One of the outcomes of the E[4] program was improved retention of engineering students, both within the College of Engineering as well as the University. The key factors that contributed to the improvement of retention may be listed as follows:

- A new and revolutionary academic paradigm was successfully created in which the general environment and all academic activities focus on the students as emerging professional engineers from the very beginning of the educational process.
- Engineering is up-front, with Engineering Design and Labs serving as the key element of experiential learning and integration of basic engineering sciences, engineering and humanities, based on projects that provide the context for engineering problem solving. Integration of theory and practice in engineering and science is perhaps the most critical factors in improving the retention rates by emphasizing the engineering experience in the first two years.
- Instructors served as mentors and facilitators to establish a community of learners.
- Close faculty-student interaction through regular meetings of student cohorts with faculty teams. Interaction creates community and strengthens esprit de corps as a "cohort of engineers." This is encouraged by the close interaction between the members of the interdisciplinary faculty team.
- The yearlong emphasis on design during the first-year begins with a "first-week" design competition held in public with general participation. This reinforces the "engineering focus" and the "team project concept" in an exciting fashion.

The E[4] program was evaluated with the voluntary participation of 800 students and 60 faculty members over a six-year period. The first part of the evaluation process was based on a variety of quantitative methods and written instruments developed by the faculty and focused on the following elements: 1) student attitudes, level of preparation, abilities and maturity, 2) effectiveness of different curricula and methodologies, and 3) internal consistency among course objectives, subject matter, methodology and student ability. The second part focused on the understanding and measuring the complexities of change processes, which involved qualitative evaluation to capture the underlying processes of the students' educational experiences. Student journals were examined, as well as in-depth interviews held for both E[4] and traditional engineering students. The results of the evaluation were very positive and showed E[4] students developed excellent to outstanding levels of communication, laboratory, and computer skills. The E[4] students also had, in general, higher grade point averages (see table 12), improved progress rates (see table 13), and higher retention rates (see figure 1) than their counterparts in the traditional program. Perhaps most importantly, many indicated in their written commentaries that they had begun to sense that the practice of the "engineering profession" would be personally exciting, rewarding, and enjoyable. A closer look at the quantitative measures compiled for the cohorts from the E[4] and traditional tracks show a clear trend favoring the performance of the

	1988 Cohorts		1989 Cohorts		1990 Cohorts		1991 Cohorts	
Term	E4	Control	E4	Control	E4	Control	E4	Control
1	2.91	2.70	2.90	2.39	2.79	2.61	3.06	2.72
2	3.01	2.70	2.80	2.36	2.90	2.50		
3	3.08	2.80	2.95	2.49	3.00	2.52		
4	3.11	2.80	2.97	2.51	2.99	2.62		
5	3.24	2.80	3.02	2.61				
6	3.22	2.95	2.96	2.68				
7	3.24	2.94						
8	3.24	2.93						

Table 12. Drexel E[4] cumulative grade point average comparison.

	1998 Cohorts		1989 Cohorts	
	E4	Control	E4	Control
On Track	58%	35%	74%	33%
Changed Major	5%	11%	1%	2%
Withdrew	9%	18%	4%	12%
Dropped	0%	7%	0%	1%

Table 13. Drexel E[4] progress comparison.

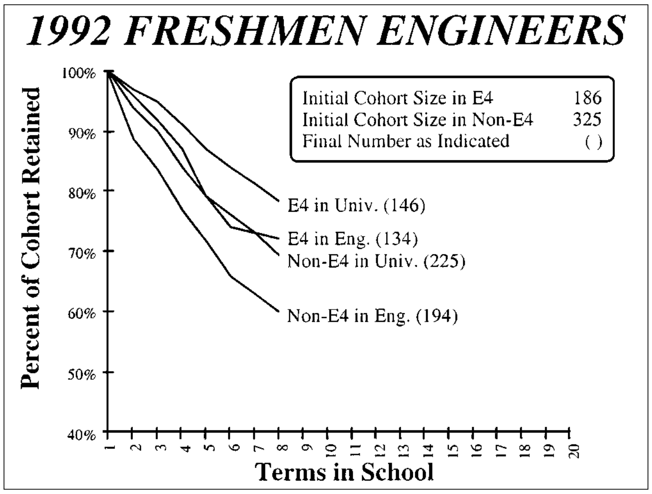

Figure 1. Retention rate of students E⁴ vs. traditional students; freshman class of 1992.

former. Table 12 compares cumulative GPA's for the two cohorts labeled E^4 and Control. The GPA for the E^4 cohort is consistently higher (between 0.21 and 0.51) than the Control cohort having similar academic backgrounds, both while they were in their separate tracks (i.e., terms 1–5) and subsequently when the classes merged following the sophomore year. Table 13 shows that for the 1988 and 1989 cohorts, the "on track" progress to degree was significantly higher for the E^4 cohort when compared to the Control cohort.

Data on retention by term (including co-op terms), for the first four freshman classes (1989–1992) show exhibit similar retention trends for the E^4 and Non-E^4 cohorts. Comparison of the final retention rates for the freshman class of 1989 (i.e., graduating class of 1995) exhibit 23.4% higher retention for E^4 students in engineering (68.4% vs. 45%), and 18.1% higher retention for E^4 students in the University (75.5% vs. 57.4%). While the E^4 students have significantly higher retention rates in both categories, it is noteworthy that the relative retention rates within engineering are even higher than within the University. It is clear that within minor statistical variations these general trends were maintained for the later freshman classes (figure 1 shows the class of 1992; additional data are available in reference 12).

VII. Conclusions

Diverse integrated first-year curricula have been piloted at a number of different schools across the engineering coalitions. Assessment results indicate a positive impact on student retention and learning. Furthermore, design alternatives have been abstracted from the different pilot projects. Institutions considering an integrated first-year curriculum should explore the different alternatives to identify a configuration that fits the student population and culture.

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