6-24-2007

The Current Generation of Integrated Engineering Curriculum

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Publisher Citation

Collura, M., & Daniels, S., & Nocito-Gobel, J., & Harding, W. D. (2007, June). The Current Generation Of Integrated Engineering Curriculum. Paper presented at 2007 Annual Conference & Exposition, Honolulu, Hawaii.

Comments

AC 2007-2034: THE CURRENT GENERATION OF INTEGRATED ENGINEERING CURRICULUM

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The Current Generation of Integrated Engineering Curriculum - Assessment After Two Years of Implementation

Abstract

In September of 2004 our university adopted the ***Multidisciplinary Engineering Foundation Spiral Curriculum*** as the basis for disciplinary engineering programs in Chemical, Civil, Electrical, Mechanical and General Engineering. The curriculum includes a sequence of first and second year engineering courses, matched closely with the development of students' mathematical sophistication and analytical capabilities and integrated with course work in the sciences. Students develop a conceptual understanding of engineering basics in this series of courses which stress practical applications of these principles.

The new curriculum was designed to provide students with a multidisciplinary perspective while developing basic engineering skills and fostering an understanding of basic engineering concepts. Each of the ten courses in the program were developed and are taught by faculty from several disciplines. Course materials are intended to make students keenly aware of the highly integrated nature of the current practice of engineering. It was also expected that the novel program would prove to be attractive to a broader range of students than those drawn to traditional disciplinary programs. Finally, student retention was expected to be enhanced by the new courses.

Students who entered as freshmen in 2004 are currently juniors, taking courses in their disciplinary major. This study attempts to provide early data on the success of the program through the following measures:

- Impact of the new curriculum on student recruiting through a survey of newly matriculated students
- Impact on student retention from first to second and second to third years
- Comparison of student performance in early disciplinary courses with that of students in previous years
- Impact of program implementation on faculty attitudes

Introduction

The need for change in the way engineers are educated has been well-established, most notably by the work of the National Academy of Engineering through *The Engineer of 2020*[1] and *Educating The Engineer of 2020*[2]. To summarize very briefly, engineering educators are being asked not only to preserve the level of analytical skill that has served society so well over the past several decades, but also to help students develop a host of professional skills and a broader perspective than has traditionally been associated with the engineering profession. At the same time, we are faced with a looming crises as the current engineering workforce ages and the number of young people interested in an engineering career declines.

In a traditional engineering program, the primary focus is on the content of a set of relatively narrow disciplinary courses, generally taught by faculty who are experts in the related sub-discipline. This generally results in a "silo" mentality among faculty, who see their role as helping students develop expertise in a single area. The development of professional skills, such as teamwork, is expected to occur by occasionally putting students into situations in which they need to employ such skills to complete their assignments. In addition, students are asked to take many math and science courses before they are introduced to engineering concepts. Again, if the focus is on content, this linear approach makes sense. However, students are often frustrated at not being able to do engineering work, as they see it, from the beginning of their academic experience. Nor do they generally appreciate the need for all that math and science, when their interest is to do engineering. Students who survive to the senior year (nationally, about half the initial freshman class) are then asked to synthesize all that they have learned in a design project, which requires teamwork, project management and communication skills, as well as the ability to see the world from a broader perspective. Note that they have spent the previous three years learning to focus on details of ever-increasingly narrow topics, with an strong emphasis on individual achievement. It is no surprise that many students have difficulty adapting to the more realistic nature of work in the senior design course.

The Tagliatela College of Engineering at the University of New Haven offers ABET accredited programs in Chemical, Civil, Computer, Electrical and Mechanical Engineering. All these programs are built on the ***Multidisciplinary Engineering Foundation Spiral Curriculum (MEFSC)***. This foundation program was developed to provide students with a broad engineering background and to develop the essential skills needed for the practice of engineering.

Previous Work

Considerable work has been done at several engineering schools to address some deficiencies in engineering education, resulting in many models of curriculum integration. The comprehensive article by Froyd and Ohland[3] traces the history and discusses the merits of various models. Drexel University, an early pioneer, established the merit of integrating math and science with engineering in its E^4 program[4]. Notable progress has been made by the NSF Engineering Coalitions[5] in introducing active/cooperative learning methods, hands-on and project-based learning, teamwork, industrial design projects, course integration and other innovations. Most of the sustained efforts have been at the freshman level, where there are often no courses in a specific engineering discipline and therefore less resistance to change. The Foundation Coalition has developed a model to transform the sophomore year into a more multidisciplinary experience. However, this model has not been adopted by many programs and is generally run as a parallel track with traditional programs where it has been adopted. This is the current situation, for example, at Texas A&M and Rose Hulman Institute of Technology, two of the more progressive engineering schools. Thus the sophomore and junior years typically are not changed significantly from the traditional model. Attempts to develop a multidisciplinary perspective by using mixed teams in senior design projects is too little, too late to truly develop the broader view. By this time the students have already adopted the strong disciplinary perspective modeled by faculty mentors.

Another approach taken by a few schools has been to eliminate traditional discipline-specific programs in favor of a broad-based general engineering program. Harvey Mudd College has used this model very successfully, allowing students to concentrate in an area, such as electrical engineering, but not with the depth developed by students taking a major in a specific discipline. While this approach has some merit, our industrial advisors strongly support degree programs in specific engineering disciplines.

Overview of Curriculum Model

The curricular model begins in the first semester and extends through the sophomore year. Courses in each engineering discipline build on this background to develop depth needed for the individual engineering degree programs. All engineering students, beginning with those entering in the fall of 2004, participate in the ***MEFSC***. The key features include:

- several courses taught from a multidisciplinary perspective
- three engineering courses available in the first year
- focus on the development of specific professional skills common to all disciplines
- spiral approach to develop engineering concepts from the major disciplines
- vertical and horizontal integration of engineering courses
- integration of engineering courses with science and math courses

Details of the program and its development have been presented in a previous paper[6] with some early funding provided by the National Science Foundation.[7] Figure 1 shows a comparison of this curriculum to a traditional engineering curriculum.

One very important feature of this curricular model is the treatment of engineering topics during the first 2 years using a spiral curricular approach. The spiral curriculum is a pedagogical construct proposed by Jerome Bruner[8] in which concepts are first introduced in a relatively simple way, then revisited again to provide a deeper understanding, perhaps several times. This approach has been proposed recently for sophomore Chemical Engineering courses[9,10,11] at Worcester Polytechnic Institute and for courses in Electrical Engineering Technology[12] at Purdue University. The courses with the EAS prefix form a spiral construct of engineering foundation topics (Figure 2) in the first three terms.

Each of the ten courses in the engineering foundation program are multidisciplinary in nature and were developed by teams of engineering faculty. In some cases, faculty from the sciences and math were also part of the development teams. Most of the courses are taught by teams of faculty from different engineering disciplines, in order to maintain their multidisciplinary character. Several of the engineering courses have been designed to integrate with appropriate math and science courses taken by the engineering students. For example, one of the sophomore courses was designed to be taken concurrently with an engineering physics course. The sequence of topics in the engineering course build on those in the physics course, emphasizing engineering applications of the physics concepts. Similarly, applications of mathematical concepts are frequently illustrated in the engineering courses. This integration is intended to help students better appreciate the role of math and science in engineering work and to motivate them in their study of math and science.

Figure 1

Comparison of Traditional Engineering Curriculum to UNH Spiral Curriculum

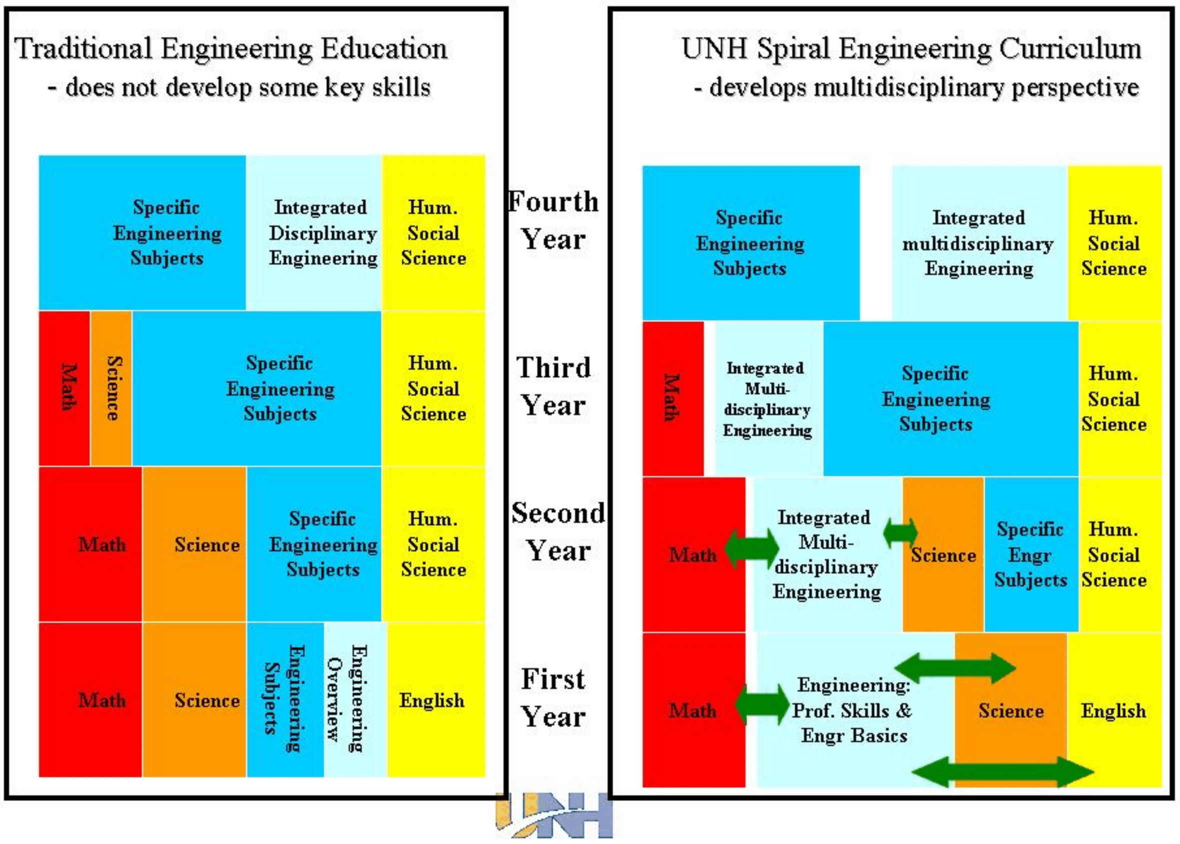
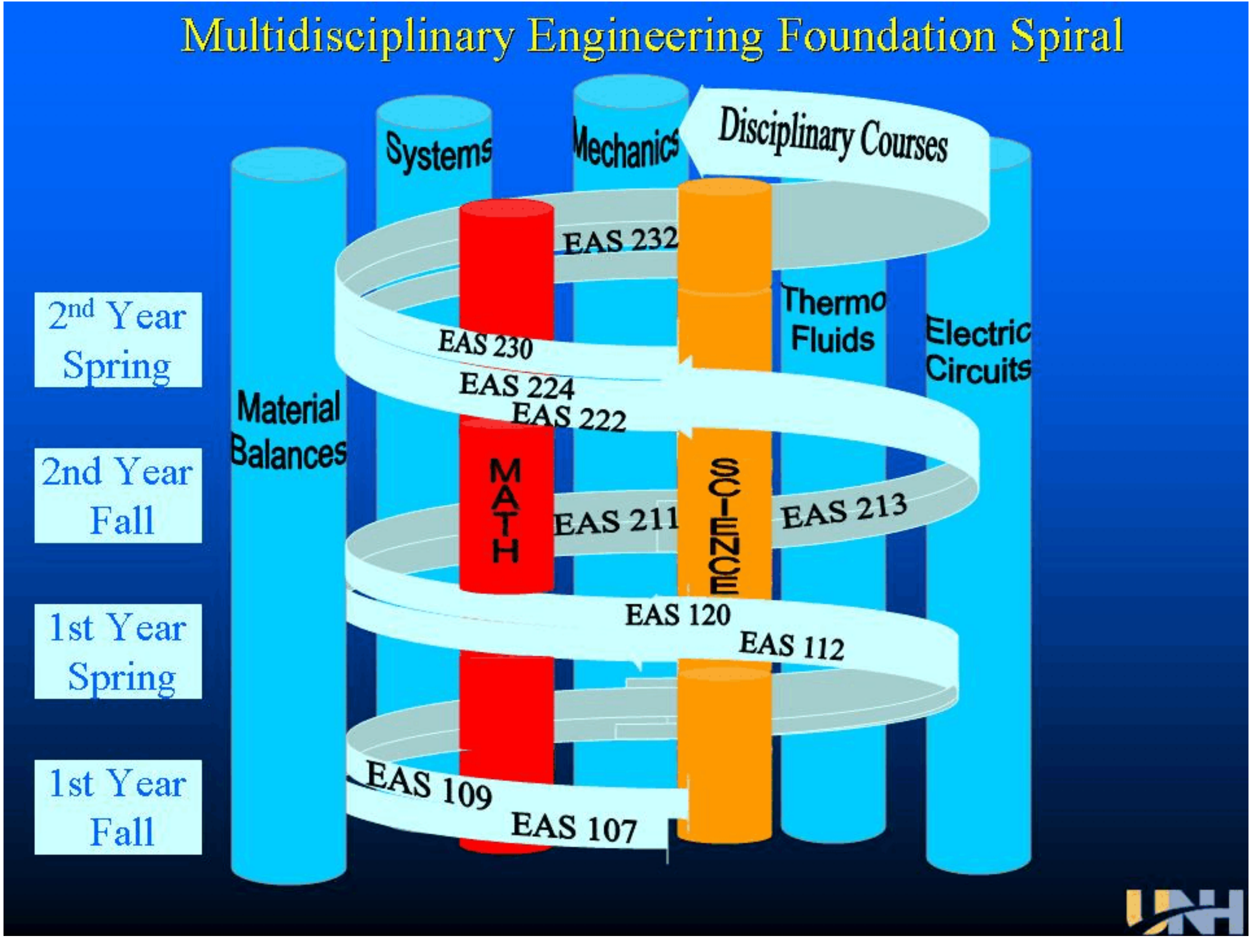


Figure 2 shows the relationship of the ***MEFSC*** courses (EAS prefix) to the engineering foundation topics. Engineering topics and professional skills are integrated both vertically and horizontally throughout the curriculum. Each course has specific objectives for engineering topics and for skill development in order to assure that students progress in both areas as they move through the programs. Careful coordination is essential to provide the topical development required to prepare students for upper-level courses in the specific engineering disciplines.

Figure 2



The overall objectives of the ***MEFSC*** are the following:

- to enhance recruiting
- to improve student retention in the first year
- to foster a multidisciplinary (systems) perspective early in students' development
- to improve professional skills needed for engineering practice, including communication, project planning, problem-solving, team-work
- to better integrate math and science into the engineering curriculum
- to provide all engineering students with a broad appreciation of the major engineering disciplines

First Year Program Description

The focus of the first year is to help students develop a set of professional skills and to introduce all students to the basic principles of the major engineering disciplines. Table 1 provides an overview of the courses. Details may be found in previously presented papers as indicated in Table 1..

Table 1 Features of First Year Spiral Engineering Foundation Courses		
Course	**Features**	**Professional Skills Targeted**
EAS 107 Introduction to Engineering - Project-Based[13,14,15]	team project based, engineering and non-engineering students	design process, oral & written communications, engineering disciplines, teamwork
EAS 109 Project Planning & Development[16,17]	several multi-week engineering projects requiring specific computer tools, planning and experimentation	personal and project management, team member and team leader skills, computer tools, applied to projects
EAS 112 Methods of Engineering Analysis[18]	problem-driven, use of spreadsheet and programming to develop algorithms to solve engineering problems	algorithm development, use of computer tools, statistics, numerical methods, programming concepts
EAS120 Chemistry with Applications in BioSystems	a second semester science course, provides background for further study of chemistry and introduces some biological concepts	laboratory taught from an engineering perspective, includes design and analysis of experiments, computer data aquisition

Two engineering courses are taken during the first semester: EAS107P, Introduction to Engineering (Project-Based) and EAS109 Project Planning and Development. Engineering topics from several areas are presented primarily in a qualitative form, with the use of computer tools to help students handle quantitative aspects. In the second semester, students take EAS112, Methods of Engineering Analysis, a computer-based course in which engineering problems are solved using spreadsheets and Visual Basic programming.

In order to broaden the science exposure beyond the typical chemistry and physics courses, a unique science course was developed for the second semester. EAS120 Chemistry with Applications in BioSystems, draws from a traditional second semester general chemistry course, but also provides an introduction to biology topics that are of interest to engineers. The lab is taught by engineering faculty using computer data acquisition equipment, with an emphasis on engineering laboratory skills.

Second Year Program Description

In traditional engineering programs, students usually are introduced to the fundamental concepts of their discipline at the sophomore level in courses such as electric circuits, statics, mass balances and thermodynamics. It is in these courses that students first encounter complex engineering problems which require a more organized approach than they may have needed in their math and science courses. Typical roadblocks to student mastery of the material in these courses include lack of fluency in using algebraic symbols to represent system properties and variables, reluctance to use diagrams to organize information, need to develop an appropriate set of equations, a focus on getting the answer rather than on applying an organized method and a lack of faith in their ability to solve complex problems. Regarding this last point, the typical student feels a need to see a clear path to solution when beginning to solve a problem. Lack of an obvious solution generates considerable discomfort and often leads to the "I'm Clueless" syndrome. The slow pace of the typical sophomore-level course is set by need to develop student problem-solving skills and to overcoming these roadblocks, not by the difficulty of the material. Thus students who enter an introductory disciplinary course having well-developed problem-solving skills are able to master the content at a faster pace. For example, when students at an upper-level in one discipline take introductory courses in another discipline, they often are able to do very well.

The first semester of the sophomore year includes EAS211, Introduction to Modeling of Engineering Systems and EAS213, Materials in Engineering Systems. EAS211 is designed to develop students' problem-solving skills by introducing engineering problems from a variety of engineering areas. Students develop mathematical descriptions of these systems using the conservation principles (conservation of mass, charge, energy and momentum) along with other constitutive equations. This course integrates closely with physics and illustrates applications of calculus. EAS213 includes coverage of gas and liquid properties, as well as traditional topics from engineering materials courses related to solids. The physical property-based approach to this course provides students with a strong understanding of material behavior, without the complexity of the typical thermodynamic, fluid mechanic or solid mechanics course. Both EAS211 and EAS213 draw on work done by the Foundation Coalition and courses offered at Texas A&M and Rose Hulman Institute of Technology. Taken together, these courses include material that would ordinarily be found in introductory courses in statics, mass balances, electric circuits and thermodynamics.

This pair of courses leads to a set of more narrowly focused courses: EAS222, Fundamentals of Mechanics and Materials and EAS224 Fluid-Thermal Systems. EAS222 completes the spiral of introductory material in the mechanics area, with coverage from statics, strength of materials and some dynamics, building on work done in previous EAS and physics courses. EAS224 does the same for the introductory courses in thermodynamics and fluid mechanics. EAS230, Fundamentals and Applications of Analog Devices, provides background in electrical circuits. It was designed to integrate with a second physics course. Finally, EAS232, Project Management and Engineering Economics, helps prepare students for work on projects in an industrial setting. The sophomore-level courses are summarized in Table 2.

Table 2 Features of Second Year Spiral Engineering Foundation Courses	
Course	**Features**
EAS 211 Introduction to Modeling of Engineering Systems[19]	problem-solving, elements of mass balances, circuits, thermodynamics.
EAS 213 Materials in Engineering Systems	gases, liquids and solids, thermodynamic, transport and mechanical properties
EAS 222 Fundamentals of Mechanics and Materials	leads to the more advances study of mechanics and structures
EAS224 Fluid-Thermal Systems	leads to the more advanced study of thermodynamics, fluid mechanics, heat and mass transfer
EAS230 Fundamentals and Applications of Analog Devices	leads to the more advanced study of electrical circuits, electronics and power
EAS232 Project Management and Engineering Economics	provides tools for economic analysis and management of engineering projects

The concept of a spiral curriculum includes the idea that topics are encountered in several courses rather than being treated from start to finish in a single course. For this to be effective, it must begin with the first semester and extend through the full curriculum. Thus the early introduction of engineering topics is done before the students have fully developed their mathematical skills. Table 3 provides a summary of how course content is matched to the student's level of mathematical sophistication.

Program Assessment

Assessment of the ***MEFSC*** must include measurements at the course and program level. Course level assessment will not be discussed here, but can be found in previous publications for several of the courses.[11-17] Program level assessment is very preliminary at this pointed and is based on a relatively small number of students. Nonetheless, some results will be presented here to illustrate the methods being used.

Table 3
Progression of Analytical Skills in Spiral Foundation Courses

Term / Course	Math Level	Science Course	EAS Context	Concept Development	Quantitative Modeling
yr 1, sem 1 EAS107 EAS109	Calc 1 or Precalc	Chem 1	hands-on projects in teams (107); project management & engineering computer tools (109)	establish conceptual base, explore effect of variables, develop qualitative understanding	use modeling packages in "black box" mode to observe relationships, while exploring design options for projects
yr 1 sem 2 EAS112	Calc 2 or Calc 1	Chemistry with Bio Applica-tions / lab	problem-driven applications in various disciplinary areas using case-studies	manipulate equations, develop familiarity with symbols	equations given to students allowing them to develop algorithms for solution
yr 2 sem 1 EAS211 EAS213	Calc 3 or Calc 2	Physics 1	simple, practical problems of industrial significance	develop quantitative understanding of basics in several engineering foundation areas	develop balance equations, select others as needed for models
yr 2 sem 2 EAS222 EAS224 EAS230	Diff Eqn or Calc 3	Physics 2	focus on smaller sets of topics, typical of those found in pairs of soph or jr level engineering courses	further develop understanding of areas specified by program, in a multidisciplinary format	develop all equations and explore areas in more depth

Since the introduction of the ***MEFSC***, we have experienced increases in enrollment in the engineering programs. Features and objectives of the curriculum have been included in recruiting literature since 2004 and are presented to prospective students at admissions events. In order to assess the impact of the ***MEFSC*** on student recruitment, an anonymous survey was conducted in the Introduction to Engineering (EAS107P) courses late last fall. Students were asked to indicate why they chose to study engineering at UNH. A summary of results is shown below:

Table 4
Excerpt from Enrolled Student Survey - Reasons for Selecting UNH Engineering
(Number of students selecting each response)

Reasons for selecting UNH (check all that apply)	not important	somewhat important	very important
Variety of majors within engineering	6	24	22
Ease of changing majors within engineering	18	21	13
Financial considerations	10	14	28
Small class size	5	12	35
Faculty focus on teaching	0	14	38
Features of my specific academic program	3	17	32
Project-based coursework	4	15	33
Engineering courses in the first year	2	14	36
Multidisciplinary engineering foundation	2	24	26
Living-learning community	23	10	19
Opportunities for relevant work (co-op, internship)	1	22	29

To identify the most significant reasons for students attending, consider responses that indicate a reason is somewhat important or very important. The reasons selected most often are the following:

Faculty focus on teaching - 100% of respondents
Opportunities for relevant work - 98% of respondents
Engineering courses in the first year - 96% of respondents
Multidisciplinary engineering foundation - 96% of respondents

About half of the respondents indicated that UNH was their first choice among the schools to which they applied. If the responses of this sub group are considered, the top reasons are similar to the above results, however, two additional reasons emerge:

Faculty focus on teaching - 100% of respondents
Project-based coursework - 100% of respondents
Opportunities for relevant work - 98% of respondents
Engineering courses in the first year - 96% of respondents
Multidisciplinary engineering foundation - 96% of respondents
Features of my specific academic program - 96%

These results appear to indicate that the new curriculum has had a positive impact on the enrollment of students in engineering. Surveys of students over the next few years will be needed to confirm this impact.

The impact of the curriculum on retention and overall student performance is summarized in Table 5 below. The sample groups used in the study include entering freshman engineering students. The University of New Haven enrolls a rather large number of transfer students, however, transfer students were not included in the study since the purpose is to assess the impact of changes in the first two years of the programs. Again, data is preliminary, since the program is still in its early stages.

Table 5
Preliminary retention and overall performance data for students

	former curriculum		transition period			new
	Fall 2001	Fall 2002	Fall 2003	03 pilot	Fall 2004	Fall 2005
Number of students in study cohort	34	43	52	19	28	37
First semester GPA	2.78	2.89	2.94	3.11	2.59	3.04
First semester credits completed	12.4	13.6	12.1	12.4	13.9	14.8
Percent of entering students retained	74%	93%	90%	100%	82%	86%
Second semester GPA	2.47	2.67	2.55	2.57	2.81	2.95
Second semester credits completed	12	13.0	13.3	14.4	14.8	13.4
Percent of entering students retained	56%	72%	83%	89%	64%	76%
Third semester GPA	2.29	2.40	2.46	2.51	2.73	2.42
Third semester credits completed	11.5	10.7	12.7	14.7	13.7	12.4

Pilot versions of three of the first year courses were run in the 2003-04 academic year, as an option for students. Performance of students who participated in one or more pilot courses are shown in the column labeled “03 pilot”. These students are included in the results for the full cohort from 2003, as well, which complicates the interpretation of results from that year. We were very encouraged by the retention data for the students in the pilot courses, which appeared higher than for other students. This trend did not continue with the full implementation of the curriculum in Fall 2004. However, that year was a particularly poor recruiting year resulting in a very small freshman cohort and poor performance by many in their first two semesters. At that time, recruiting literature sent to these students did not include mention of the new curriculum in any significant way. It is interesting to note that the GPA in the third semester appears to be higher than the average over the time of the study - perhaps because the poorer performing students withdrew, as indicated by the relatively low retention into the sophomore year.

Overall, this preliminary data shows no clear impact on student retention. Perhaps the best way to look at the data is to contrast Fall2005 with Fall 2002, since the intervening years were times of transition. There is a small difference in overall student performance, as measured by GPA and the number of credits earned in each of the first three semesters, generally showing better results for the new curriculum. This will be analyzed for statistical significance, but not in time for this paper.

One important objective of the ***MEFSC*** is to better integrate science and math into the engineering curriculum. If students better understand the role of physics in engineering and see direct connections to material in their engineering courses, it is expected that they will perform at a higher level in their physics courses. Table 6 reports the average grade for engineering students in their first calculus-based physics course (PH150, Mechanics, Heat and Waves).

Table 6
Engineering Student Performance in First Physics Course

	former	transition		new
	Fall 2002	Fall 2003	Fall 2004	Fall 2005
grade in PH150 - average	2.7	2.6	2.6	2.91
grade in PH150/semester GPA	0.91	1.0	0.9	1.15

Since there may be differences in student ability, a number of methods of normalizing student performance were considered. Here, the physics grade was normalized by dividing by the student's GPA for the semester in which he/she took the physics course. The resulting ratio can be viewed as an index of how well the student has performed in the physics course in comparison to his/her average academic performance. Unfortunately, not all students take courses in the optimal sequence. In this case, the ideal situation is to take the first physics course during the sophomore year concurrent with EAS211 Introduction to Modeling of Engineering Systems, since the latter course was designed to integrate with physics.

This preliminary data indicates that students appear to perform better in their physics course with the curricular integration model of the ***MEFSC***. Again, if the Fall 2005 cohort is compared to the Fall 2002 cohort, there is a higher average grade for the newer group. When normalized to the semester GPP, it shows as about a 20% improvement. This is supported by anecdotal evidence from Physics faculty, who noted that the current students are doing much better in lab work compared to non-engineering students and previous engineering students. The faculty attribute this to better team-work skills. They also commented that the engineering students have much less difficulty with kinematics topics than in the past and that they appear to do better at problem-solving.

A survey was also conducted of the students in the engineering course which was designed to integrate with physics (EAS211, Introduction to Modeling of Engineering Systems). One set of questions asked for the students perception of the interaction of EAS211 with math, physics and other engineering courses. Results are presented in Table 7 for offerings of the course in the Fall 2005 and Fall 2006 semesters. About half of the students who took the course completed the survey: 15 and 21, respectively in the two terms. Note that students were allowed to select more than one response for each subject area, so the percentages will not sum to 100.

From these results it appears that a large majority of students found the attempts to integrate with physics to be helpful to their understanding. It is interesting that some students find such integration confusing. This may be due to minor differences in nomenclature, sign conventions, etc., and bears further investigation. Care was taken in the course this fall to point out some of these differences in conventions during the course. The percentage of students indicating confusion was lower, possibly due to improvements made to address their concern.

Table 7 **Students Perception of the Impact of Course Integration - EAS211**						
How did EAS211 integrate with these courses	Math		Physics		Engr	
	F06	F05	F06	F05	F06	F05
Reinforced understanding of	67%	40%	67%	67%	38%	73%
Further developed topics from	19%	20%	14%	73%	52%	67%
Significant overlap, but not helpful	5%	20%	10%	0	10%	7%
Overlap caused confusion	5%	0	5%	20%	14%	7%
Not much overlap	14%	13%	5%	13%	19%	20%

Faculty who teach physics have indicated that they have noticed an improvement in the performance of engineering students in the past couple of years. They have also commented that the current engineering students seem more comfortable working in teams and doing lab work in comparison to other students. Attempts will be made to more formally assess these faculty perceptions.

A significant question that remains to be investigated is how well does the ***MEFSC*** prepare students for upper-level courses in their discipline, compared to a traditional approach. Since the first group of students in the curriculum have just entered their junior year, very little data is yet available. The intent is to identify specific courses in each discipline which build on the background provided by the ***MEFSC***. For example, for the Mechanical Engineering program, the following courses are the first disciplinary courses taken by the students:

Mechanics Stem: building on the EAS sequence culminating with EAS222	Thermo-Fluids Stem: building on the EAS sequence culminating with EAS224
ME300 Rigid Body Dynamics	ME305 Engineering Thermodynamics
ME308 Applied Elasticity	ME321 Incompressible Fluid Flow

Based on a relative small sample, a preliminary comparison can be made of the performance of students in two of these courses.

The comparison group in the table above is a combination of part-time and transfer students. The normalized grades use the student's GPA from the term in which the course was taken (Fall 2006). This data was not available for many of the students in the comparison group for ME321, so no normalized average is reported.

Table 8
Comparison of MEFSC to Other Students in Junior Level ME Courses

	MEFSC Students	non-MEFSC Students
Average Grade in ME 300	3.01	2.62
Average Normalized ME Grade	1.06	0.95
Average Grade in ME 321	2.83	2.76

Again, with a small number of students (14 to 16) it is not possible to draw firm conclusions. All that can be said is that the background provided by the ***MEFSC*** does not appear to place the students at a disadvantage when they reach junior level courses in their discipline. In the case of ME300, the ***MEFSC*** students appear to have done somewhat better than their counterparts.

Conclusion

A number of assessment metrics have been identified to determine if the ***MEFSC*** meets the stated objectives. Many of the objectives cannot be effectively measured yet, as the first students in the program are just entering the junior year. Preliminary results are very promising. There does seem to be some positive impact on student recruiting. The program does not yet seem to have had much impact on student retention. Several measures of performance such as Grade Point Average and number of credits earned, show promising trends that students perform better.

Much work remains to be done both to improve the curriculum and to expand the assessment metrics. Consideration is being given to the use of various concept inventories and exams of the type used for the Fundamentals of Engineering Exam used for licensing purposes. This must be balanced with test saturation. It is our hope that we can define metrics which integrate into normal course delivery and avoid excessive testing beyond what is required to assess course level performance. Careful use of self-assessment by students and sampling of faculty perceptions will augment the formal testing.

The ultimate test of the curriculum will occur when graduates are employed in industry. Since most of the objectives of the curriculum relate to preparation for practice, the most meaningful assessment will occur when graduates are using the knowledge and skills they have developed. We do have students who work part-time in engineering positions and who have done co-op assignments. There is strong anecdotal evidence that the curriculum has prepared they well for these challenges.

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