Improving First-year Engineering Education

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Abstract

The University of Massachusetts Dartmouth (UMD) began a successful, thirty-one credit, integrated first-year engineering curriculum in September 1998. The program was modeled after many of the most effective and innovative programs in the NSF-sponsored Foundation Coalition as well as from other universities and colleges. The new program at UMD includes

- *integrating the introductory sequences in physics, calculus, chemistry, English and engineering*
- *teaching and using teamwork among students and faculty*
- *using a specially designed technology oriented classroom*
- *using active and cooperative learning methods*
- *encouraging formation of a community of students by block-scheduling classes and grouping students in the dorms*
- *reducing the cost of delivering courses by making more efficient use of instructional time*
- *using careful assessment to evaluate performance.*

This paper describes the new curriculum, some of the practical considerations in its design, and the way it has functioned. It will also give a detailed snapshot of assessment results after one semester of operation. Additional assessment data on the second semester will be provided in the presentation and upon request.

Introduction

The development of the new first-year engineering program at the University of Massachusetts Dartmouth began with a review of the educational literature. It indicated that we should be able to improve first-year education while also reducing instructional time.

The literature is consistent, and often overwhelming, in the following conclusions [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]:

- Active and collaborative learning techniques can result in higher performance and longer information retention compared to the traditional methods.
- Integrating math, science and engineering courses is an effective means of teaching students to deal successfully with cross-disciplinary problems.
- Integrating English into engineering, science and math courses is an effective way to improve the performance of engineering students in oral and written communication.
- Integrated first-year programs improve retention rates, especially of women and minorities.

In addition, there was evidence at Rensselaer Polytechnic Institute that studio classes using hands-on, collaborative learning could cost less than the traditional lecture-recitation-laboratory classes [11]. Better efficiency in first-year classes would free faculty time for use elsewhere.

Where possible we have made use of insights gleaned from educational research and we have built our new first-year program on the best work already underway. Excellent curricula, courses and methodology were found at several institutions, but the NSF-sponsored Foundation Coalition was an especially productive source of understanding. Their desired educational outcomes were almost identical to ours [12]. Ours included

- improved learning in the fundamentals
- improved teamwork skills
- improved communication skills
- improved cross-disciplinary problem solving
- reduced attrition rates
- improved recruiting, especially of women and minorities
- higher success rates for students with nontraditional backgrounds.

The focus of the UMD effort has been to create and implement an effective educational package that would maximize results in the desired outcomes while lowering instructional time. That package involves integrated curricula, teaching methods and institutional processes inside and outside the classroom as described below.

Please refer to [13] for a detailed description of the new courses and the strategy used at UMD to efficiently develop, fund and implement the new program. The description below will focus on the way the new curriculum has functioned. It will also describe assessment results and their implications.

The UMD Integrated Curriculum

The new 31 credit IMPULSE (**I**ntegrated **M**ath, **P**hysics and **U**ndergraduate **L**aboratory **S**cience, **E**nglish and Engineering) curriculum is shown in Table I. A pilot of the first integrated 17 credits began in the fall of 1998 for 48 first-year engineering students. The second set of 14 credits in the sequence began in the following semester.

The new courses have been carefully sequenced to maximize synergism between them. For example, math topics are frequently taught just before they are used in physics so that physics problems serve to motivate calculus understanding. Projects in the engineering courses have often served to motivate work in both physics and calculus. Furthermore, they have also motivated essays in English.

All of the courses use hands-on technology in the classroom to assist learning. They also teach students to work in teams and use cooperative learning methods in the classroom.

The instructors teach a cohort of 48 students who take all of the courses together. Each teaches in his or her subject, assisted by a Teaching Assistant.

Classes are formally scheduled in a block that meets four hours per day, five days a week. Within that block, faculty can vary the class meeting times and the number of hours as needed in each subject from week to week.

Table I. The IMPULSE Curriculum

	Credits	
IMPULSE Freshman Courses	**Fall**	**Spring**
Physics for Sci. & Engr. I, II	4	4
Principles of Modern Chem. I, II	3	3
Intro. to Applied Chem. II	0	1
Critical Writing and Reading I	3	0
Intro. to Applied Sci. & Engr. I, II	3	2
Calc. for Applied Sci. & Engr. I, II	4	4
IMPULSE Total Credits	**17**	**14**
Program Specific (not IMPULSE)	**0**	**3**
Freshman Year Total Credits	**17**	**17**
IMPULSE Sophomore Courses		
Calc. for Applied Sci. & Engr. III	4	

The faculty in the program work as a team and typically meet each week to discuss their plans for the next week. They teach topics with full knowledge of each other's plans. Perhaps most importantly, they discuss student team problems and develop coordinated strategies to promote positive changes in student behavior and performance.

About 60% of IMPULSE students lived in the dorms. They were housed together in the dorms to encourage development of a sense of community and to promote group study.

Practical Considerations

The project was run at full size in a studio format. Intense development effort had to be directed toward perfecting classroom methods that would be effective for 48 students in the studio format. We already knew what systems could work for class sizes in the twenties because these had been run in other courses at UMD. The full size pilot put maximum pressure on the instructors, methodology and even classroom design in order to expose size related problems.

Forty eight (48) students were randomly selected from the 50 engineering majors who passed the entrance exams for both English and calculus. Student pressure to get into the program was substantial and every student invited to enroll accepted. Several students decided to forgo AP credits in English or calculus to take part.

Some compromises in the level of integration were necessary for practical reasons. Seventeen credits is a very high load for some students. The chemistry course is not tightly integrated into the other courses so that a student could drop it if necessary to reduce his or her load. The 14 credits of integrated English, calculus, physics and engineering can only be dropped as a unit because of tight sequencing and integration. Separate grades are recorded for each course even if there are some graded items shared between courses. Surprisingly, only one student dropped any course during the first semester and that student dropped out of all courses in the middle of the semester.

The topics taught in the new courses approximately match the traditional courses so that a student will be well prepared to take later courses with the traditional prerequisites. The one exception is the second course in calculus. It had to be dramatically altered to include some multivariate calculus required in physics. This material would ordinarily be in the third course. IMPULSE Calculus III had to be developed to cover the material remaining in the three-course sequence.

Students are placed in the traditional curriculum if they fail one or more courses in the integrated sequence, cannot take at least a 14 credit load, or if they have credit for an assortment of courses that are not compatible with IMPULSE. Fortunately, the traditional courses are part of the required curriculum for math and science majors and are therefore always available.

Operation

All classes, except chemistry wet labs, are taught for a single cohort of students in the same well equipped, multipurpose classroom that seats 48. The room was completely renovated and equipped as a technology-assisted learning studio based on a successful Foundation Coalition room design at Arizona State University [14].

Students at UMD work at tables that seat two on each side. At each end are a computer, a high-resolution display and a measurement interface. Students can work in teams of two on computer problems or interactive exercises. They can also work in a team of four to do a complex experiment in physics, calculus or engineering and then display and analyze the results in a short time. This configuration also proved ideal for collaborative writing and editing in English.

IMPULSE physics met four studio hours per week for mixed lecture and workshop physics group experiments. Traditional classes met for six class hours total, including three hours of lecture, one hour of recitation and two hours of lab per week [15].

IMPULSE calculus met four studio hours per week with mixed lecture and group computer exercises [16]. Traditional courses were also four hours per week but were not in a computer-equipped classroom.

IMPULSE chemistry made considerable use of computer activity as well as computer study aids and on-line quizzes [17, 18]. The first IMPULSE chemistry course met for three studio hours per week. While there was no formally assigned lab, the class included two wet lab experiments built into the course. The second IMPULSE chemistry course met for three hours of studio, one hour of laboratory lecture and two hours of laboratory. Traditional chemistry classes met in both semesters for three hours lecture, one hour of recitation, one hour of laboratory lecture, and two hours of laboratory.

IMPULSE English met three hours per week in the computer equipped studio classroom. This was a marked change in pedagogy from the standard English composition courses that meet only one hour out of every three in a computerized classroom.

The first engineering and applied science course, EGR 103, was developed to provide an introduction to engineering and applied science, develop skill in Computer Aided Design (CAD), and motivate students to learn physics, calculus and English. It taught and used teamwork and required oral presentations. Students learned to think, visualize and reason in 3-D and designed complex objects with multiple parts. They also did multidisciplinary design projects. The course met in the studio classroom for three hours per week.

The second engineering course, EGR 104, had a mechatronics theme. It was designed to continue introducing engineering and applied science while providing motivation for student learning in the second courses in physics and calculus. It met in the studio classroom for two hours per week.

Three department-specific traditional courses were replaced by these two engineering and applied science courses. The goals of these courses are quite varied so that comparisons with IMPULSE are difficult and will not be included here.

Increased Efficiency

If 96 students were placed in each program in the first semester at UMD, IMPULSE courses would require 23 instructor contact hours less per week than the traditional program. This large savings is generated because the IMPULSE studio format is more efficient with instructor time per student. Laboratory and hands-on experience occurs in the classroom without separate laboratory classes. In addition, IMPULSE does not involve separate recitation classes.

There are several additional savings involved with the IMPULSE studio format but they are more difficult to quantify. For example, IMPULSE eliminates the need for a large number of small lab and recitation sections so there are reduced scheduling and logistical costs.

Assessment

Considerable assessment and evaluation has already been done on the IMPULSE program but measurements are being made on a continuing basis using a variety of measurement devices. Some data, such as retention numbers, will not be available for another six months.

The data summarized here represent an early snapshot of the results available from the first semester pilot. Data obtained later will be given in the conference presentation and will be sent to those who make an email request.

Most of the data presented below are summarized in table form in Appendix A for convenience.

Control Groups: After a study of the factors that correlated with academic performance of first-time-full-time freshman engineering majors from 1997-98, we developed two matched comparison groups. These groups matched IMPULSE students in their calculus placement entrance test score (CP) and high school GPA as follows:

- IMPULSE – 48 engineering majors, CP=70.4%, H.S.GPA=3.03
- F'98 control – 42 science, math and engineering majors, CP=69.2%, H.S.GPA=3.01
- F'97 control – 38 engineering majors, CP=69.2%, H.S.GPA=2.99.

The F'97 control would have been IMPULSE students if the program had started a year earlier.

The F'98 control group contained very few engineering majors. We have made several studies of calculus data from 1997 and 1998 and the analysis so far supports the use of science majors for comparison groups to assess the performance of engineering students. None of these studies indicates that engineering freshmen perform differently than science or math majors in calculus. These studies are being extended to include physics courses.

Student Success Rates in the First Semester: Students in IMPULSE earned substantially more credits during the first semester than either of the control groups. IMPULSE students earned an average of 15.83 credits per student while the F'98 control earned 10.58 and the F'97 control earned 12.45 credits per student. IMPULSE students attempted more hours, 17.0 credits compared to 14.5 for F'98 control and 14.66 for the F'97 control.

The larger number of credits earned by IMPULSE students is even more significant since they were taking three very difficult courses at the same time – physics, chemistry and calculus. The control groups took chemistry and calculus but not physics. In the traditional programs, engineering majors typically take physics in their second semester and most science majors take it in their third semester.

Calculus: IMPULSE students scored an average 76.7 compared to a 62.3 for the F'98 control group on 18 common exam questions on the final exam for all sections of the first calculus course. Only 4% of IMPULSE students did not take this final compared to 28% of the F'98 control. The average grade for all traditional sections was 64.3 and 22% of those students did not take the final.

Physics: Fair comparison among the physics courses is difficult. IMPULSE students are the only students who were taking physics during the first semester of their freshman year. Data are, however, available for the following comparison groups:

- F'98 physics class – 92 students who took PHY 113 that semester (36% were engineering majors, 37% were freshmen)
- S'98 physics class – 117 students who took PHY 113 that semester (73% were engineering majors, 82% were freshmen)
- S'97 physics class – 74 students who took PHY 113 that semester (72% were engineering majors, 82% were freshmen)

Comparison is further complicated because the IMPULSE development caused changes in the way traditional physics classes were being taught. Active learning techniques were first introduced in the spring of 1998 and exercises similar to the IMPULSE physics were introduced into the standard physics course in the fall of 1998.

IMPULSE students had a normalized gain on the Force Concept Inventory [19] of 30% for the pre-test/post-test pair. The S'98 physics class (using some active learning methods) had a 25% normalized gain while the S'97 physics class (using traditional methods) had an 18% normalized gain. The F'98 physics comparison class (made up of only 37% freshmen) scored a normalized gain of 32% but only had 60% of enrolled students take the final compared to 98% in IMPULSE. The exact percentages not taking the final are not available for the S'97 and S'98 classes.

Chemistry: For many years chemistry students have taken a standardized exam, the general chemistry exam from the American Chemistry Society (ACS), as a common segment of their final in first semester chemistry. In a study of first-semester chemistry courses in the fall of 1997 and 1998, no significant differences in ACS scores were found when IMPULSE students were compared with other students who were similar in calculus placement scores. This was impressive since IMPULSE students spent only three hours per week in chemistry class rather than the traditional seven hours of lecture, recitation and laboratory.

English: Pre-course and post-course writing samples were taken from about 1/3 of all ENL 101 students in the fall of '97 and '98. IMPULSE students were included in the testing in '98 and they made a substantially larger gain than the general population. We are studying this data further to understand its statistical significance and reliability.

Engineering: As discussed above, the IMPULSE courses were so different from the department specific courses that no direct comparison of course results was attempted. Assessment in the new courses is directed toward continuous improvement of the new program.

Discussion

Our assessment results so far appear to be similar to those found in other integrated programs [7,8] that have involved more students over several years.

While our assessment data so far is very positive about the performance improvement produced by the IMPULSE program, it also indicates that opportunity exists for further improvement. Results in the literature in physics, for example, indicate that the methodology used in IMPULSE is actually capable of better results relative to traditional methods than we have seen so far. Our traditional courses produced gains on the Force Concept Inventory which were very similar to traditional courses in a study by Redish [20] which were centered at around 19%. Our active learning courses, including IMPULSE, raised our gains to 30-32%

while the active learning distribution in the study was centered at around 42%.

Experience at other universities has indicated that our scores will likely improve as our instructors become more adept with active learning methods. With assessment providing insight into performance, a process of continuous improvement is starting to develop in the IMPULSE program that should move the program toward even better results.

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Appendix A

Summary of IMPULSE Assessment Data

	IMPULSE N=48	F'98 Control N=42	F'97 Control N=38	Traditional All Enrolled
Success Rates				
No. credits earned	15.83	10.58	12.45	
No. hours attempted	17.02	14.50	14.66	
No. quality points earned	44.06	31.03	34.89	
Calculus				
18 common exam questions (F'98)	76.7***	62.3***	N/A	64.3***
Percent students taking final (F'98)	95.8%	72%		78%
Percent W, D, or F	33.3%	43.6%	35.1%	38.8% (F'98) 37.4% (F'97)
Physics				
Normalized gain on Force Concept Inventory	30%*	N/A	N/A	32%(F'98)* 25%(S'98) 18%(S'97) 17%(F'96)
Percent students taking final	98%	N/A	N/A	60%(F'98)
Percent W, D, or F	4.2%**	N/A	10.7%** (taken in S'98)	12.5%(S'98)** 48.4%(F'98)**
Chemistry				
ACS Normalized Exam Score	76.8****	Numbers of students too small for analysis	Numbers of students too small for analysis	69.0 ('98) **** 72.0 ('97)
Percent W, D, or F	29.2%	30% (N=10)	23.7%	39.4% (F'98) 36.1% (F'97)

*This comparison is weighted against the IMPULSE class because:
- (a) 98% of IMPULSE students took the final whereas only 60% of the F'98 class took the final.
- (b) The IMPULSE students are first-year first time students whereas only 37% of the F'98 class were freshmen, and
- (c) Active learning was introduced into the laboratory for the F'98 class so there was less difference in learning experience.

** The IMPULSE class, and the S'98 class had the same instructor. This instructor provided extensive tutoring and exam retake opportunities in the traditional classes. The F'98 traditional class was taught by a different instructor who used some active learning techniques, especially in the laboratory.

*** This comparison is weighted against the IMPULSE class because of the larger number of students in the comparison group who did not take the final.

**** The average ACS normalized exam score for IMPULSE students is higher than the score for all other students enrolled in Chemistry 151 in 1998. However, no statistically significant differences, are found when IMPULSE students are compared only to other subgroups who also passed the calculus placement test.