Efficient Development and Implementation Of An Integrated First Year Engineering Curriculum

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Abstract - *In September 1998, the University of Massachusetts Dartmouth (UMD) began a pilot version of a fully integrated first year engineering curriculum totaling 31 credits. The new curriculum is cost-effective and has a high probability of successfully improving the learning of engineering freshmen as well as their retention.*

This paper outlines strategies that brought the new curriculum efficiently into being and helped to assure its success. Many of these were learned by studying work done in the NSF-sponsored Foundation Coalition as well as at other schools. Where possible, we have built on the best work of those who have already developed successful, innovative teaching methods and curricula.

The paper briefly outlines the courses and teaching methodology in the new integrated curriculum. It also describes the studio classroom and equipment that have been optimized for hands-on, technology-assisted learning.

Introduction

Until the fall semester of 1998, the first year curriculum for engineering majors at the University of Massachusetts Dartmouth (UMD) was similar to that at most universities. Textbooks and courses were frequently revised to keep up with new technology but teaching methods had been little changed for decades. The traditional lecture style of presentation was used almost exclusively and lecture class sizes of over a hundred were common in important introductory courses. Smaller recitation classes were often used for problem sessions, but the instructor usually worked problems at a blackboard or overhead projector without much student participation.

For the present generation of students, these traditional methods have not been working well. There were some significant symptoms at UMD, as at most universities. For example, more than a third of students were not present during many large lecture classes. In spite of a large university sponsored tutoring program, over 40% of students would typically drop, fail, or get a D in the first calculus course. In chemistry, this number was 52%. To achieve a lower failure or withdrawal rate in physics, some instructors adopted a time consuming strategy of extensive tutoring and exam retakes.

The attrition rate in engineering was correspondingly high. For example, of the first year engineering majors in the fall of 1995, 39% were not in engineering in the fall of 1996. Moreover, despite the high failure and drop rates in the first year, instructors for later courses frequently commented about the poor preparation of students and their lower performance and motivation compared to students of a decade ago.

The declining motivation and performance of engineering and science students prompted a group of faculty at UMD to search for solutions. This faculty team wanted to determine what could be done to improve learning in the introductory sequences in physics, calculus, chemistry, and English since these courses form the foundation of students' academic and professional careers. They also wanted to implement desirable changes as quickly as possible, but in a way that would be robust and durable.

Building On the Best Work

Fortunately, when we began studying the problem, researchers had already done considerable experimentation with alternative teaching methods and curricular organization. Some have demonstrated significant improvement in learning, retention, and motivation [1-7].

At the outset, we decided to learn about curriculum innovations and change processes directly from people already involved. Papers offer considerable insight; however, they often do not tell about difficulties or failures. Personal contact with teachers as well as visits with students in working classrooms allowed us to learn about successes as well as problems. In addition, we learned what concerns we might expect from faculty, students and administrators and how to address them. Most importantly, we discovered many costly mistakes to avoid (such as overloading students).

Our research identified several successful, innovative programs that appeared to be adaptable to UMD. In particular we approached people from institutions in the Foundation Coalition at a national conference of the American Society for Engineering Education. That coalition of seven universities and colleges is one of several sponsored by the National Science Foundation (NSF) [8, 9]. Its programs have demonstrated significant improvement in student performance. Furthermore, their objectives and results closely matched what we were trying to achieve.

People in the Foundation Coalition were very open and generous in their offers of assistance. Six of our team went to one of the Foundation Coalition universities, Texas A&M, for two days in October 1996 to study their integrated first year program. A faculty member from Texas A&M subsequently traveled to UMD to give presentations to faculty and administrators and to conduct a workshop on cooperative learning. From these visits and from email and telephone conversations with several people across the Foundation Coalition, we learned a great deal about the practical aspects of delivering a freshman program and motivating an institution to make such a massive change. We also learned important techniques for building outcomes assessment into the project.

In addition, we arranged a one-day visit to see Rensselaer Polytechnic Institute's Studio Calculus and Studio Physics programs [10,11]. These merge lecture and laboratory activities in the classroom. That trip was also enormously productive and worthwhile because we were able to see classes in action and discuss the pros and cons with instructors.

Based on these visits and further study of published work, our faculty team constructed a basic plan in October 1996 to fully develop and implement a freshman program. The plan proposed a first year engineering curriculum which integrated nearly all of the courses normally taken by freshmen. The new curriculum was designed to be cost-effective with a high probability of successfully improving learning. It employed subject integration, technology-assisted cooperative learning, and student teamwork, as in Foundation Coalition models. It also used hands-on, technology-assisted learning in studio type classes similar to those at Rensselaer.

In general, the new curriculum exploits the best techniques we saw or studied while avoiding many of the pitfalls we had come across (see the Appendix for a brief discussion of the new curriculum).

Efficient Implementation: Obtaining Internal Support by Getting External Support

Development of a sound curriculum plan was only part of the solution. Successful curriculum innovation has at least as much to do with motivating faculty and administration outside the activity as it does with developing excellent courses and curriculum. Several basic strategic decisions were made to optimize the likelihood that the new freshman program would be implemented and to insure that it would remain successful over a long period.

Obtaining sufficient support and resources was an enormous challenge. Funds as well as faculty and administrative time were fully committed to programs that were already in place. It was going to be extremely difficult for a new program, no matter how promising, to win an internal competition for resources.

The faculty team decided that the best way to get internal support was to first obtain external support. This would give the program credibility among faculty and administrators. Furthermore, the process of obtaining external support would build commitment within the administration even if we did not obtain a grant for 100% of the funding required. As a minimum, we needed sufficient funding to give the project momentum.

We decided to look to private foundations first because the approval cycles were typically simpler and shorter than those of a government agency. We submitted a proposal seeking $180,000 in funding from a foundation that contributes only to New England colleges. The proposal would require substantial UMD matching funds. It was fully funded in December 1996.

This level of funding gave the project enormous momentum. Furthermore, during the publicity from the grant, nearly everyone in the administration chain of command, including the Chancellor and Provost, made public commitments to the success of the project.

Preparing Faculty and Others for Change

With so many courses, departments, and colleges involved in the project, the earliest the new program could begin was in September 1998. We needed a minimum of one year to plan the details of the integrated courses and to provide for faculty training in new methods. Furthermore, we had to communicate with faculty in the departments involved and across the campus to increase acceptance of the project. It was especially important to keep anxiety low and to avoid surprises.

We realized that faculty resistance could be a serious hazard to the new program. According to well-known marketing lore, people have to see and hear things multiple times before there is an impact on their actions. Recognizing that, the principal investigator of the project began a systematic program to help faculty understand that there were alternative methods of teaching and organizing curricula that could possibly be better than traditional methods.

The new program was named IMPULSE (**I**ntegrated **M**ath, **P**hysics and **U**ndergraduate **L**aboratory **S**cience, **E**nglish and Engineering) to make it more easily identifiable. Every two to four weeks the attention of engineering faculty was directed to some aspect of the IMPULSE project or the value of curriculum reform. This ranged from meeting with departments to placing brief progress reports or copies of articles in faculty mailboxes.

Furthermore, every few months a well-known speaker was brought to campus for presentations or workshops open to faculty from any college. Presenters included Roger Johnson on cooperative learning [1], John Gardner on the first year [12], and Priscilla Laws on Workshop Physics [13]. Several excellent speakers from the Foundation also visited campus. For example, Jeff Froyd described results from the integrated first year program at Rose-Hulman and P. K. Imbrie and Cesar Malave from Texas A&M provided a comprehensive workshop on teaching teamwork to students.

In addition, affected departments at UMD were consulted frequently regarding concerns and fears about IMPULSE. This involved actively trying to locate resistance and then identifying and resolving any underlying, sometimes hidden, agenda. Typical issues ranged from workload concerns to fears of losing control of a course.

By offering IMPULSE as a pilot with planned assessment and correction over time, we were able to keep serious resistance down. Each department could choose whether to have their students participate and every participating department was guaranteed a voice in the assessment and feedback processes that would determine how the program would be improved. This reduced fears considerably because no department would give up control when the curriculum actually began. It also provided incentive to be involved.

Designing for Long-term Effectiveness

It is common for educational innovations to die when particular people are no longer involved. This was a real concern. The IMPULSE curriculum was designed to include features that would make it robust and would encourage its extension into more of the engineering and science curricula. Specifically we designed the curriculum to:

1. **Lower the cost of delivery.** This is a powerful incentive for college Deans to keep the program going and to enlarge it. The new hands-on studio sections of 48 students have a lower cost of delivery than traditional courses at UMD. This is easy to understand for English courses with a typical section size of 25; however, studio classes are also less expensive to deliver than the traditional lecture hall, recitation and laboratory class combination typically used in the sciences. When there are 96 students taking a total of 31 credits of IMPULSE courses with each class taught by an instructor and a TA, the university will save an estimated $124,000 per year.
2. **Build in thorough, accurate assessment.** This is critical to the lasting success of the curriculum because it will drive future improvements and provide insight for good decisions. Assessment data about the overall performance of courses is the only effective counter to misinformed judgments based on a few students' poor performance in later classes. We expect performance data to show significant improvements that will encourage other faculty to adopt the new methodology.

   Assessment in IMPULSE courses will be both formative and summative. Control groups will be established using a cluster method on baseline pre-test scores, high school rank, and SAT scores. Comparisons will be made between IMPULSE students and the control groups on the Force Concepts Inventory Test [14] and the Mechanics Baseline Test [15] as well as common exam questions, student and faculty surveys and limited exit interviewing. In addition, writing samples before and after the first semester will allow us to evaluate the effects of the new integrated teaching methods on writing skills
3. **Build on faculty teamwork.** Faculty members function as a team in IMPULSE. This provides long-term stability in the curriculum because the methodology is rooted in the team, not in a single member. In order to maintain this stability, however, the number of new teachers in the program each year must be kept small and allowance has to be made for training new members.
4. **Pilot full size sections.** Full-size pilot courses cause instructors to develop and tune their teaching methods at the outset for the appropriate number of students. In addition, assessment data provides direct insight into the performance that would be seen when the pilot courses move into the required program. We used a pilot size of 48 students because it was the section size ultimately desired in the freshmen program at UMD.
5. **Have a scale-up plan**. For a lower division curriculum to become mainstream, it must deal with all of the special cases that arise because of transfer students, AP credit and students who leave school but return after various lengths of time. In order to have at least one reasonable solution, a plausible plan was sketched that would include all students in some version of IMPULSE during scale-up. This was done informally before starting the pilot to make sure that the basic plan was not fatally flawed.

Conclusion

The process of development and implementation has been efficient and has proceeded relatively smoothly at UMD without major difficulties or surprises. Still, the development and implementation of the IMPULSE curriculum evidences the large effort required when making a substantial change in teaching methods and curricula.

Seeking advice and help from people who were already making progress in the kinds of things we wanted to accomplish helped us develop a well-focused program. We used that to successfully seek external funding which provided the catalyst we needed to launch the program forward. In addition, we realized early that in trying to change curricula and teaching methods in the first year, we were actually trying to change the culture of the university, or at least a substantial part of it. By viewing it that way, we were better able to make progress and to understand the need for frequent two-way communication with faculty members and administrators.

Appendix: The IMPULSE Curriculum

The new 31 credit IMPULSE curriculum for freshmen is shown in Table I. A pilot of the first 17 credits began in the fall of 1998. The second integrated set of 14 credits in the sequence will begin in the following semester.

Table I. The IMPULSE Curriculum

	Credits	
IMPULSE 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**

The topics taught in these integrated courses approximately match the traditional courses so that a student will be well prepared to take later courses with the traditional prerequisites. However, the new courses will also teach students to work in teams and will make extensive use of cooperative learning methods and hands-on technology in the classroom to assist learning.

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 in the classroom.

The faculty in the program work as a team focused on organizing presentations, assignments and topics in all courses for optimum educational effect. Classes are formally scheduled in traditional blocks from 8 AM to 12 noon, five days a week; however, the amount of class time for each course varies from week to week. The instructors meet each week to finalize the schedule for the next week and they teach topics with full knowledge of each other's plans. Whenever possible they pick exam questions, problems, and examples from the other courses to tie them together in students' minds. Similarly, instructors routinely give written and oral presentation assignments in all subjects and coordinate those with the English instructor.

The IMPULSE Classroom

All classes, except chemistry wet labs, are taught in the same well equipped, multipurpose classroom. This room was completely renovated and equipped as a technology-assisted learning studio based on a successful room design from Arizona State University which was built as part of their Foundation Coalition effort [16]. Forty-eight students at UMD work in teams of two or four on high-speed computers that have sophisticated measurement devices, interfaces, software, and displays. In a very short time, students are able to do a complex experiment in physics, calculus or engineering and then display and analyze the results.

IMPULSE Engineering

Based on our reviews of collaborative programs in the Foundation Coalition, we decided to require an engineering course each semester to provide engineering motivation for the other courses. These engineering courses use design projects to involve students in the process of using physical devices and materials to solve problems. The projects require that students integrate knowledge from all of their courses.

The first course introduces graphics and involves substantial multidisciplinary design project activity to help develop spatial reasoning as well as motivation for the other integrated courses. Projects in the first course emphasize Newtonian mechanics appropriate to the first semester of physics. The projects require that students carry out computer dynamic simulations using 2-D and 3-D tools to check for interfering parts before they implement their designs.

To help students understand how good design applies science to solve a problem, the course uses several sources including the *Secret Life of Machines* videotape series [17]. The approach was motivated by a multimedia design case study course taught at Tuskeegee University as part of the NSF Synthesis Coalition effort [18-20]. Each videotape focuses on a product such as the internal combustion engine, the quartz watch or the sewing machine. Each team views two videotapes approximately five weeks apart and does a presentation that includes hand-sketched and computer graphics. The tapes are also subjects for English assignments on process writing.

In the second course, we decided to use a mechatronics theme [21] because of the electromagnetic emphasis in that semester of physics. Students will study and use electrical and electromechanical components, measuring devices, sensors, and actuators, as well as logic and data acquisition devices. They will carry out short projects in the classroom and each team will complete two major projects.

IMPULSE Physics

In topic coverage, the new physics courses differ very little from the traditional courses and use the same textbook [22]. However, what happens in the classroom is very different. Hands-on activities are an important part of most classes and there are no separate laboratory and recitation sections. For example, during a typical physics class after a short lecture, groups of two to four students work together on a problem which requires measurements followed by evaluation of results. They use devices interfaced to their computer to make accurate, fast measurements and record them directly in a spreadsheet. Then they quickly plot and analyze the data and compare it to theoretical models and write their conclusions or present them to the class.

The new IMPULSE physics courses have been closely patterned on the successful Workshop Physics developed at Dickinson College [12]. We chose this approach because it is a carefully developed and extensively tested, hands-on, active-learning curriculum. As we develop experience in these teaching methods and obtain our own assessment data, we will further optimize the course as needed.

Equipment for two semesters of Workshop Physics was chosen to provide flexible activities for 48 students working in teams of two to four. Pasco Model 700 interfaces with software and probes permit rapid measurement and analysis of linear and rotational motion, force, acceleration, voltage, current, magnetic field, temperature and pressure.

IMPULSE Calculus

How many times have math instructors heard students ask, "When will I ever use <u>this</u>?" The integrated curriculum provides an immediate answer to that question: "You'll use it tomorrow in your physics or engineering class to solve an applied problem." Integration with physics and engineering simply makes calculus more relevant.

Coordination of calculus with physics and engineering necessitated the reordering of topics and affected the entire three-semester calculus sequence. While the third semester is not part of the IMPULSE program, a new calculus course will be available for IMPULSE students in their third semester.

After study of alternative approaches and numerous meetings among the IMPULSE instructors, the team agreed to use the following guidelines to change the way calculus is taught in the first two semesters:

- Put more emphasis, earlier, on the concepts and applications of the derivative and integral.
- Put more emphasis on using technology for curve sketching and solving problems.
- Add an introduction to vectors, line integrals, double and triple integrals, and flux.
- Add 3D graphing using technology.
- Use the reform calculus rule of four: present topics geometrically (graphically, visually, dynamically), numerically, analytically, and verbally.
- Have students do more oral presentations and writing about mathematics.
- Use less rote drill.
- Reduce emphasis on multiple analytical techniques of integration.
- Reduce emphasis on tests for convergence of series and put more emphasis on the use of series.

In order to make the teaching methods more effective, we use a reform calculus approach, use cooperative learning, and integrate technology throughout. We chose the text by Hughes-Hallet [23] because of its strong development of calculus concepts.

A variety of software packages were reviewed and Maple [24] was chosen because of its universal use by all Foundation Coalition schools, its popularity in academia in general, and the abundance of mathematical materials specifically written for it [25, 26].

IMPULSE Chemistry

We learned from people in the Foundation Coalition that 17 credits of tightly integrated courses would present a problem for some students. Any who fell seriously behind would need the safety valve of dropping a course to reduce load. For this reason, chemistry in the new curriculum can be dropped without dropping any of the other courses. That is not true for the rest of the IMPULSE curriculum. Therefore, the integration of chemistry is nearly one directional. The chemistry instructor can make efficient use of material already presented in the other courses but not vice versa.

The topics covered in the IMPULSE chemistry courses parallel those in the traditional program; however, the new courses emphasize applications to the properties of materials to motivate engineering majors. Again, cooperative learning methods and technology assisted learning in the classroom and laboratory are used extensively.

In addition, while there is no credit specifically for wet-laboratory activities in the first semester, IMPULSE chemistry will include them as necessary to prepare students for the second semester, which does include a one credit wet-lab. The IMPULSE chemistry wet-lab also has computers and rapid measurement devices so that students do experiments faster, more accurately and with less tedium.

IMPULSE English

As in all sections of first semester freshman English, the primary concern is with gaining command of the grammatical conventions needed for constructing essays geared toward a range of popular and professional audiences. IMPULSE English differs, however, because the textbooks [27, 28] and assignments are designed to improve the motivation of engineering majors to express their ideas in written and oral form. Assignments focus on problems in science and engineering and two of the four major papers call for analysis of the ethical issues that sometimes confront scientists and engineers.

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