Engineering Physics: The Universal Donor Degree

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Introduction

The ABET-accredited B.S. Engineering Physics program at the Colorado School of Mines has enjoyed major expansion in recent years - growing from 108 majors in 2000 to 230 majors today. Physics is now the fourth largest undergraduate program on campus. This growth followed three events: (1) curricular reform which reduced the overall credit load and concentrated most of the electives in the senior year, (2) the establishment of three 5-year programs that lead to a B.S. in Engineering Physics and an M.S. in a traditional engineering discipline, and (3) a vigorous marketing effort that emphasized the advantages of a course of study that offered a solid foundation in physics concepts and math literacy coupled to a wide mix of applications and practical hands-on experiences. The general applicability of physics fundamentals along with great curricular flexibility have allowed our Engineering Physics degree to become the "Universal Donor" degree for post-graduate studies in science or engineering. While contributing to our growth, these reforms have presented special challenges to our assessment/feedback program with so many different curricular and career paths for our students. This paper describes the program and discusses our approach to assessment/feedback as we prepare for our next ABET visit in 2006.

New Paradigm for Undergraduate Engineering Education

Engineering has evolved considerably in the last 40 years. In 1960 there were a handful of undergraduate engineering disciplines. Civil, industrial, electrical, mechanical, or chemical engineering accounted for nearly all engineering bachelor degrees. An engineering bachelor's degree provided the apprentice engineer with the skills necessary to begin a career. With the great leaps in technical advances and increasing complexity in the world today, modern engineering practice has entangled the old disciplines and blended in new ones. This has necessarily placed greater emphasis on interdisciplinary teams and higher levels of education. To function effectively, such teams need leaders with breadth and depth of technical understanding as well as leadership and communication skills.

In addition, the information revolution has transformed the skill sets needed by our future engineers and when combined with the challenges of the global economy, has forced engineering educators to examine anew their curricular goals. Sophisticated software packages can now do much of the basic grunt work performed in the past by the apprentice engineer. As a result, the goals for engineering education should emphasize capabilities in what computers cannot do. One such area is creative engineering.

Creative engineering occurs at the leading edge of technology where new science and new technical abilities meet to enable new ways of solving problems or creating new products. Instilling such talent in engineering graduates is a very ambitious goal, but one worth attempting. Central to the model presented here is the recognition that creative engineering will require higher levels of education. The idea that the master's degree is a more appropriate entry-level engineering degree is not new, but is embraced here as the key underlying assumption to our program. Once one is thinking in terms of graduate degrees, the question for the undergraduate program becomes, “What is an optimal set of knowledge and thinking skills appropriate to a 4-year bachelor's degree that prepares a student for a broad range of technical graduate fields?” Our answer is Engineering Physics (EP), and our story is about curricular and instructional reforms that enabled this intrinsically interdisciplinary degree to be the “Universal Donor” for advanced degrees in engineering and applied science.

Institutional and Departmental Profile

You start at home. No degree program can succeed without the support of its home institution. Whatever success our EP program enjoys derives principally from its alignment with the fundamental role and mission of the institution. CSM is a small, state-assisted, technical research university whose mission is focused in energy, materials, and resources. The school has about 3,000 undergraduates with 230 teaching faculty. While the school has a viable graduate research program, the principal focus has traditionally been on the undergraduate component. Of the 11 undergraduate degrees, 8 are in ABET-accredited engineering disciplines, including our Engineering Physics program. While still serving its traditional resource industries, today CSM has a diverse set of engineering and applied science programs. Although the Mining Engineering major is a small fraction of our undergraduate student body, we are proud of the traditions reflected in our name which embodies the ethics of hard work, technical proficiency, and self-reliance.

The Physics Department manages three degree programs: B.S. Engineering Physics and the M.S. and Ph.D. Applied Physics. It has 17 full-time faculty, 40 graduate students, 230 undergraduate EP majors, and conducts about $2M in sponsored research annually. With the strong emphasis in applications, the department has developed close relationships with the traditional engineering programs and conducts multi-departmental interdisciplinary research through the Materials Science program and two research centers (Center for Electronic and Solar Materials and the NASA Center for the Commercial Applications of Combustion in Space). These close relationships were critical to creating the atmosphere of trust and respect necessary for the coordinated degree programs discussed below to function effectively.

Universal Donor Degree

CSM's B.S. Engineering Physics degree is one of 17 such programs accredited by the Accreditation Board for Engineering and Technology (ABET). Our last general review took place in 2000 under the Engineering Criteria 2000 (EC2000), and our next review will occur in 2006. As is by now well known to the engineering education community, under EC2000, accredited programs must identify their constituents and implement a process for developing program goals and objectives, as well as a delivery plan that makes use of assessment and feedback to demonstrate continuous improvement.

To identify our constituents we looked at where our students went after graduation. We learned that a majority of our graduates ended up pursuing engineering careers instead of the more traditional route of graduate studies in physics. Discussions with our engineering faculty colleagues revealed their deep appreciation of the special insights and thinking skills shown by the engineering physics students who continued their graduate studies in their engineering fields. Informal discussions eventually led to several formal 5-year combined B.S./M.S. degree agreements. In these combined programs a student could earn his or her B.S. Engineering Physics degree in four years, and, if meeting quality requirements and taking a prescribed sequence of courses for the electives, can also receive a master's degree in an engineering discipline in just one additional year. Currently, we have 5-year program agreements in electrical, mechanical, and materials engineering.

There were two principal reforms that made these 5-year agreements possible. First, we reduced the total number of credit hours in the physics program such that the prospect of a student taking an overload was not out of the question. Excluding our 6-credit summer field session, our program consists of 124.5 credit hours, averaging just 15 credits per semester in the junior and senior years[1]. A traditional physics program will contain core elements from mathematical physics, intermediate mechanics, intermediate electricity and magnetism, thermal and statistical physics, quantum mechanics, electronics, and advanced laboratory methods. We compressed these traditional core physics courses into the sophomore and junior years leaving seven electives in the senior year. These curricular changes coupled with a high level of technical literacy typical of physics students provided the flexibility needed to allow motivated students to pursue a wider spectrum of engineering and applied science graduate tracks.

The first track is for the 30% or so of our students intending to go directly to an industry. Colorado microelectronics and defense industries are common employers of our EP graduates. In this case the senior year electives are selected from specific engineering science and design courses needed for entry level in the target industry. Someone interested in working for one of the local defense companies, for example, might take elective courses in fluid dynamics, computational methods, advanced materials, or other courses that are useful to the industry and complement his or her physics background. Because we are a broadly-based nontraditional engineering program, most traditional engineering courses fit very nicely into our elective set. An example curriculum of this track appropriate to the defense industry is given in Table A2 in the Appendix.

Our second track, serving about 50% of our graduates, is for those students seeking to enter the engineering profession at a higher level. Some, but not all, such students are attracted to one of our 5-year programs which allows them to attain this goal efficiently. In developing these programs, we worked with the respective engineering faculty to determine the courses needed to fulfill the Engineering Physics degree requirements as well as prepare the student for graduate studies in that engineering discipline. Our students have become an excellent graduate recruitment pool for the engineering disciplines since Engineering Physics students generally perform very well in their engineering graduate studies. Indeed, those EP students maintaining a B-average in this program gain automatic admission to their prospective graduate program. In addition, by aligning their senior design activities properly, these students can complete their (nonthesis) masters degree in just one additional year. These tracks have proved very popular with our students, attracting almost 50% of our majors. An example curriculum of this track appropriate to electrical engineering graduate school is given in Table A3 in the Appendix.

Finally, about 20% of our students intend to pursue graduate studies in traditional physics. For these students we choose the electives in selected physics topics to round out their background. Such courses include advanced mathematical physics, solid state physics, astrophysics, and nuclear physics. We find that these students are generally competitive at gaining admissions to quality graduate physics programs, and, with their extensive design and hands-on experience, they bring an extra dimension to their physics graduate school training that enables them to "hit the ground running" when they join research groups.

Since the Engineering Physics option is serving so many different engineering and applied science constituencies, like O-negative blood, we think of it as the "Universal Donor" for advanced technical degrees. The basic Engineering Physics curriculum along with example elective choices for two example tracks are given in the Appendix.

Curricular Features

There are two special features of the CSM Engineering Physics curriculum which are worthy of note. The first is the school-wide requirement of a summer "field session". Almost unique to CSM, this tradition dates back to the school's origins where mining engineers were literally taken to an operating mine for on-the-job training. In the physics program we use this occasion to train our students in a wide set of laboratory skills: vacuum systems, thin films, CAD, machine shop, optical design, instrumentation, and computers. Taken in the summer between the sophomore and junior years, the field session runs for six weeks. Once through this intensive training, the students have the necessary skills to be useful in research labs and often find employment in research labs. Another principal benefit of the summer field session is the high level of camaraderie developed and friendships formed among the students. After this intensive experience, the students have bonded into a cohort physics class. These relationships help sustain the students through the challenging junior year curriculum.

The other notable curricular feature is the senior design capstone experience. While well-known to any ABET-accredited engineering program, senior design is uncommon to the 750 non-ABET-accredited physics programs. It is in the senior design experience the students apply their technical laboratory skills and broad physics background to open-ended problems often in the research groups. To the extent practical we use the senior design sequence as an opportunity for a true undergraduate research experience. By directing senior design students into the physics research laboratories, we align the teaching mission with the research interests of the faculty thereby reducing the natural tension that exists in faculty at research universities between research and teaching.

Senior design begins with the student selecting an area of interest and then meeting with individual faculty to select a senior design advisor and define a target project. The topics range widely. Recent example projects include fabrication and characterization of back contacts for photovoltaic cells, design and fabrication of special components for a vacuum system to study quantum dot nucleation, designing a sulfur lamp system for pumping a laser, and designing and fabricating a novel high-flux alpha detector for the Joint European Tokamak. Often, the better projects are reported at professional society meetings and some find their way into refereed publications. Students participating in one of the 5-year programs can conduct their senior design work in the engineering department in which they expect to earn their M.S. degree.

As with any complicated interconnected design problem, there have been compromises. Compressing the core advanced physics courses makes the junior year especially challenging. Faculty teaching these courses have found it necessary to expand their office hours and help sessions to accommodate slower students. To allow room in the curriculum for the wide variety of courses needed to meet the three career tracks, our EP students will typically take fewer "traditional" physics courses. For example, our students will take only one semester of formal quantum mechanics, and they are not *required* to take the standard set of physics courses such as optical physics, solid state, or nuclear physics (although many *elect* to take such courses). Coordinating course schedules with other departments has proved a challenge as well.

Recruitment

As the adage goes, it is not enough just to build a better mousetrap; one must also market the idea to the appropriate audience. CSM is a state institution; drawing roughly 70% of the student body from instate with an average SAT around 1240. However, for the purposes of this report, the most important student characteristic is their nearly universal predisposition toward engineering and science. This narrow focus enables a long institutional core, covering the first three semesters and affording an opportunity to influence student decisions regarding their major. In particular, since the institutional common core includes Physics 100 (Mechanics) and 200 (Electricity and Magnetism), the opportunity also exists to recruit quality students. We take advantage by placing excellent teachers in these classes and devoting considerable attention to improving the introductory course pedagogy. This has been fairly effective as indicated by a student survey which found that roughly half of our EP students were inclined to a different major when they started.

Another important marketing effort involves working closely with the institution's admissions officers. The school sponsors three large recruitment events in which the Physics Department fully participates. During these events, the Department will host a few hundred prospective students and their parents, giving tours and explaining the various career paths available to our graduates. The school also requires a special orientation course called the “Freshman Success Seminar” in which one of the requirements is to attend presentations by three different departments.

Finally, while the curricular reforms and marketing efforts enabled the possibility of our “Universal Donor” vision, it is the quality and commitment of the faculty that makes it happen. In general, by the nature of the discipline, physics programs are intellectually challenging which can intimidate prospective students; we cannot change this fact. However, the physics faculty have developed a reputation for nurturing and caring for their students that has given the program a positive “buzz” in the wider student population and which has contributed significantly to the growth in majors.

In a survey of our students who were NOT predisposed to physics as their major when they matriculated: 71% said they were attracted to the fundamentals of physics while nearly 80%

said the faculty had a reputation for caring for their students; a smaller fraction, 52%, said they choose physics because they believed it would lead to a good job.

Assessment and Feedback

One essential component of EC2000 is assessment and feedback leading to continuous improvement. Our assessment/feedback efforts are organized around three overlapping feedback loops: individual courses, program learning objectives (curriculum and instruction modes), and overall program goals. Each level has a characteristic time scale associated with it. The individual courses are assessed with each offering with feedback affecting the next offering. Each instructor maintains a course assessment notebook which documents this effort. The notebook is designed to be minimally intrusive, making extensive use of assessment materials already available, but including some documentation demonstrating "closing of the feedback loop".

The program learning objectives are reviewed annually by the Department's undergraduate committee with changes implemented on the scale of a few years. This committee also organizes the biannual faculty undergraduate retreat where the entire curriculum is reviewed and opportunity for horizontal (within a given term) and vertical (between terms) feedback occurs. The undergraduate committee and the Department Head oversee the feedback implementation.

The overall program goals are reviewed by the Department's External Visiting Committee every three years with changes expected on the time scale of a decade. In addition to these activities, feedback is provided by the engineering division faculty member who is charged with coordinating the 5-year programs. This person also assists in student advising. Other assessment activities include alumni surveys and other forms of end-user feedback. With the undergraduate focus of the institution already part of our academic culture, the faculty readily accepted this outcome-based approach as a valuable tool to improve our educational programs.

Summary

The fundamental knowledge and problem-solving skills of engineering physics graduates ensure their success in a broad array of engineering and applied science careers. To exploit the flexibility of the EP degree, the CSM Physics Department reformed its curriculum to accommodate a large variety of career options. These reforms included reducing the number of credits required for the degree and compressing the physics major core courses to allow seven electives in the senior year. The basic physics background and elective flexibility enables a broad spectrum of options. Among these options are three 5-year programs whereby capable and motivated students can earn a B.S. in Engineering Physics in 4 years and an M.S. degree in just one additional year. As a result of these reforms and a targeted marketing plan, the CSM EP program has more than doubled in 4 years to over 230 majors, roughly 8% of the undergraduate student population. The breadth of technical career and graduate school options available to our engineering physics graduates demonstrates it is indeed the "Universal Donor" degree. Under the right conditions, notably an institutional emphasis on science and engineering, some nominal level of curricular flexibility, and faculty buy-in, the EP success story could be repeated elsewhere.

[1] For details regarding the CSM Engineering Physics curriculum, 5-year programs, and assessment program visit the URL: http://www.mines.edu/Academic/physics/undergrad_pgm.

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APPENDIX: Example Curriculum Tables

Table A1: Basic Engineering Physics curriculum. Note the concentration of electives in the senior year.

Year	***Course***	***Year***	***Course***
Freshman I	Calculus I	***Freshman II***	Calculus II
	Chemistry I		Chemistry II
	Humanities I		Quant. Lab
	Earth & Env.		Physics I
	Freshman Seminar		Design I
	Physical Activity I		Physical Activity II
Sophomore I	Calculus III	***Sophomore II***	Differential Equations
	Physics II		Thermodynamics I
	Design II		Physics III
	Humanities II		Analog Circuits
	Physical Activity III		Economics I
			Physical Activity IV
Summer	Apparatus Design		
Junior I	Math Physics	***Junior II***	Thermodynamics II
	Inter. Mechanics		Inter. Electromagnetism
	Advanced Lab I		Intro. Quantum Mechanics
	Digital Circuits		Advanced Lab II
	Humanities III		Free Elective
Senior I	Senior Design I	***Senior II***	Senior Design II
	Adv. Electromagnetism & Optics		Humanities V
	Humanities IV		Technical Elective
	Free Elective		Free Elective
	Free Elective		Free Elective

Table A2: Example elective selections (*italics*) for a student preparing to enter the defense industry. The first two years are the same as shown in Table 1A.

Year	***Course***	***Year***	***Course***
Junior I	Math Physics	***Junior II***	Thermodynamics II
	Inter. Mechanics		Inter. Electromagnetism
	Advanced Lab I		Intro. Quantum Mechanics
	Digital Circuits		Advanced Lab II
	Humanities III		*Computer Programing*
Senior I	Senior Design I	***Senior II***	Senior Design II
	Adv. Electromagnetism & Optics		Humanities V
	Humanities IV		*Heat Transfer*
	Fluid Dynamics		*Feedback Control Systems*
	Mechanics of Materials		*Engineering Elective*

Table A3: Example elective selections for a student preparing to enter graduate school in an electrical specialty. The first two years are the same as shown in Table 1A.

Year	***Course***	***Year***	***Course***
Junior I	Math Physics	***Junior II***	Thermodynamics II
	Inter. Mechanics		Inter. Electromagnetism
	Advanced Lab I		Intro. Quantum Mechanics
	Digital Logic		Advanced Lab II
	Humanities III		I*nformation Systems*
Senior I	Senior Design I	***Senior II***	Senior Design II
	Adv. Electromagnetism & Optics		Humanities V
	Humanities IV		*Feedback Control Systems*
	Electric Machinery		*Electrical Engineering elective*
	Electronic Devices and Circuits		*Electrical Engineering elective*

Table A4: Example elective selections for a student preparing to enter graduate school in physics. The first two years are the same as shown in Table 1A.

Year	***Course***	***Year***	***Course***
Junior I	Math Physics	***Junior II***	Thermodynamics II
	Inter. Mechanics		Inter. Electromagnetism
	Advanced Lab I		Intro. Quantum Mechanics
	Digital Logic		Advanced Lab II
	Humanities III		*Astrophysics*
Senior I	Senior Design I	***Senior II***	Senior Design II
	Adv. Electromagnetism & Optics		Humanities V
	Humanities IV		*Nuclear Physics*
	Graduate Quantum I		*Graduate Quantum II*
	Solid State Physics		*Quantum Optics*