Outcomes of a Chemical Engineering Option within a General Engineering Program at a Liberal Arts College

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Introduction

Hope College is a small liberal arts college of approximately 3,000 students with nationally recognized programs in the sciences. Over two decades, the physics department progressed from offering a few engineering courses to the development of an ABET-accredited general engineering program.

The renamed physics and engineering department began offering coursework in chemical engineering in 2002-03. Engineering became a separate department during the 2006-07 academic year and it currently offers emphasis options consisting of a set of elective courses in chemical, biochemical, and environmental engineering, as well as emphasis options in mechanical, civil, electrical, and computer engineering. This presentation details the development and structure of the chemical/biochemical/environmental engineering options with a focus on their unique features and the outcomes of program graduates.

The number of chemical engineering graduates has grown from one or two students per year in the first three graduating classes from 2005 to 2007 to five in 2008. Eleven class of 2011 sophomores are currently following the chemical engineering course sequence. Two of the first four graduates are currently enrolled in Ph.D. programs and another is in an M.S. program. Over 80 percent of students in the option participated in a significant undergraduate research experience before graduation.

Another major strength of the program is its natural implementation of multidisciplinary engineering experiences in projects and coursework for students. Some of these ideas may be adaptable to traditional chemical engineering departments in their efforts to promote multidisciplinary experiences. Challenges include limited faculty and laboratory resources, lack of visibility for a small new program, and the constant quest to fit the “square peg” of chemical engineering into the “round hole” of general engineering.

Background on Hope College and its Engineering Program

Chartered in 1866, Hope College is a distinguished and distinctive four-year, liberal arts, undergraduate college, affiliated with the Reformed Church in America. The curriculum offers a variety of courses in 90 majors leading to a Bachelor of Arts, Bachelor of Music, Bachelor of Science, or Bachelor of Science in Nursing degree. During the 2007-08 school year, Hope had 3,226 students from 45 states and territories and 31 foreign countries. [1]

Hope’s science programs have long been recognized for their excellence. As many as six departments in the sciences – biology, chemistry, computer science, geological and

environmental sciences, mathematics, and physics and engineering – have held grants through the NSF-REU program simultaneously. Hope has frequently held more of the grants than any other liberal arts college in the country, and more than all but a handful of institutions of any type — including research universities — nationwide. [1]

The college's program in the sciences and mathematics was recognized as a "Program That Works" by Project Kaleidoscope of Washington, D.C., and identified as a model for other institutions to consider. The Research Corporation ranked Hope eighth out of 136 institutions in research publications per faculty member from 1991 to 2000. [1]

According to a study of 518 baccalaureate institutions released by Franklin and Marshall College, Hope ranked in the top six percent in the nation in producing future Ph.D. holders between 1920 and 1995. The department of chemistry was in the top one percent. Data collected by the National Center for Education Statistics of the Department of Education and reported in Chemical & Engineering News showed that Hope produced more chemistry graduates than all but one other undergraduate liberal arts college nationwide between July of 1999 and June of 2000. [1]

A report from the National Science Foundation placed Hope in the top 25 nationally among baccalaureate colleges as a source of future Ph.D. recipients in the natural, physical and social sciences, and engineering, after examining the undergraduate origins of doctorate recipients from 1991 to 1995. Hope ranked third nationally in chemistry, and 14th in psychology. [1]

Hope tied for fourth nationally in the "Undergraduate research/Creative projects" category in the America's Best Colleges 2003 guide published by U.S. News and World Report for its success in teaching through active learning. [1]

Engineering courses have been offered at Hope College since 1979. Initial offerings were instituted by the Department of Physics in response to academic interests of students who were majoring in physics but whose career goals were in engineering. At that time, two faculty members, with interests and training in engineering, began offering a limited number of courses in basic mechanical and electrical engineering topics. During the decade of the 1980s, these courses included Solid Mechanics, Electronics, Thermodynamics, Fluid Mechanics, Material Science, and Vibrations. This curriculum was designed and intended to prepare students for graduate study in engineering. Another option for engineering students was the Hope College Engineering 3-2 Program in which students combined three years of study at Hope College with two years at a traditional engineering school. Upon successful completion of this program, students received a Bachelor of Science degree from Hope College and a Bachelor of Engineering degree from the engineering school. [2]

A Bachelor of Science degree with a major in Engineering Physics was established in 1989. The objective of this degree program was to improve the preparation of Physics students for engineering graduate school. In order to meet the requirements of this new major, the curriculum was modified to offer engineering courses on an alternate year basis. This arrangement allowed efficient use of the existing engineering faculty to provide students with a course pattern which more closely resembled that of a traditional four-year engineering school. As a result of these improvements to the engineering curriculum, the popularity of the 3-2

Program diminished as a majority of engineering students decided to remain at Hope College for four years to pursue a major in Engineering Physics. Most of these students continued their studies in engineering graduate school, although a fair number of students began pursuing employment in industry directly from Hope College. [2]

In 1994, the engineering faculty increased to four members through the addition of two new hires. This growth was partially supported by a grant from the Fund for the Improvement of Post-secondary Education (FIPSE, administered by the Department of Education), which was granted to the college to develop a model for engineering programs at liberal arts colleges. The educational objectives of this expansion were to implement a capstone engineering design experience, provide core engineering classes on an every-year basis, and to increase the number of engineering topics courses offered. These objectives were successfully achieved with the implementation of several changes. These included the development of a two-course capstone sequence in engineering design, the switch of Thermodynamics and Fluid Mechanics from alternate year to every year basis, the development of a freshmen engineering course, and the offering of topics courses in engineering such as Finite Element Analysis, Multi-body Dynamics, and Advanced CAD/CAE. [2]

From 1994 to 1997, as part of the FIPSE-sponsored study of the Engineering Program, a number of external reviewers from both small and large engineering colleges served as external advisors to the Engineering Program. Based partly on their largely positive reviews of the Engineering Program, the Department requested permission from the administration of Hope College to pursue an ABET-accredited engineering degree. Approval was granted in 1997, and the Department established a new degree designation: the Bachelor of Science with a Major in Engineering. This new engineering major was designed and intended to fulfill the degree requirements as specified by the ABET 2000 criteria. In 1998, the Hope College Curriculum Committee officially approved the new engineering major, and the Department of Physics changed its name to The Department of Physics and Engineering. [2]

The engineering program completed and submitted a self-study to ABET and underwent a visit and review during the Fall 1999 semester. In 2000, The Bachelor of Science with a Major in Engineering was accredited by the Engineering Accreditation Commission of ABET, 111 Market Place, Suite 1050, Baltimore, MD 21202-4012, telephone: (410) 347-7700. [2]

In 1997, a fifth engineering faculty member was hired, and in 2001, 2002, and 2005, the department filled vacancies by hiring faculty members with expertise in electrical engineering, chemical engineering, and civil/structural engineering. Additional elective engineering topics courses were added to allow students to select among emphasis options in mechanical, electrical, chemical, computer, biochemical, civil, or environmental engineering. [2]

Design and Structure of the Chemical Engineering Emphasis Option

Prior to the development of the elective emphasis options, the Hope College engineering program focused on mechanical engineering topics and to a lesser extent,

electrical engineering topics. Few students indicated an interest in chemical engineering. Those who did typically completed coursework for the engineering major and a chemistry major or minor. Because not all the courses overlapped, these students needed 20 or more additional semester credits beyond the 126 required for graduation at Hope. Furthermore, those students who did complete dual degrees in chemistry and engineering found themselves unprepared for chemical engineering graduate school or industrial positions. They lacked background in mass and energy balances applied to chemical processes, advanced thermodynamics, separation processes, reaction engineering, and other chemical engineering topics.

A chemical engineering emphasis option was designed beginning in 2002 and first appeared in the 2003-04 college catalog under the Bachelor of Science Major in Engineering. Like the existing mechanical and electrical emphasis options, the chemical emphasis was designed to meet ABET requirements for coursework in engineering topics and science topics. The development of the chemical emphasis faced two unique challenges. First, it needed to integrate with the existing engineering courses, taking advantage of overlapping topics where possible. Second, it needed to integrate with the extensive general education requirements of a liberal arts college.

The degree to which these challenges shaped the chemical emphasis option at Hope is illustrated in Table 1. The data for other institutions in Table 1 were compiled as of early 2003 and do not reflect curriculum changes at those institutions since that time; however, the data for Hope have been updated to reflect current requirements.

In this table, the semester credit hours in various topics were tabulated for thirteen chemical engineering programs chosen from three groups. (One school used a quarter system and its credits were converted to semester credits for the table.) Comparisons were made to the Hope engineering program for non-chemical emphasis students and the Hope engineering program for chemical emphasis students.

Topics were categorized as general education (GenEd) if they were general education or liberal arts course credits required of all students for graduation, exclusive of natural science and mathematics topics outside of engineering (Math/Sci). Required engineering topics credits (Engr) were a separate category. The final two categories were technical elective credits (TechElec) which were allowed to be selected from either math, natural science, or engineering topics, and free elective credits.

The first two comparison groups were based upon the 2003 U.S. News & World Report rankings of engineering programs at schools without a Ph.D. program in engineering. The first four schools – Rose-Hulman, Cooper Union, Bucknell, and Manhattan – were listed among the top five chemical engineering programs. The second four schools – Villanova, Minnesota-Duluth, Calvin, and Widener – were additional schools with a chemical engineering program that were listed among the top 50 engineering programs. The final five schools – Michigan, Michigan State, Wayne State, Western Michigan, and Michigan Tech – were all other schools in Michigan that offered chemical engineering programs.

Of the thirteen benchmark schools, only Calvin had an emphasis option within a general engineering program similar to the one being designed. All the others had separate chemical engineering programs, in most cases as their own departments.

Table 1. Benchmarking the Distribution of Topics in Chemical Engineering Programs.

School	Semester hours in					
	GenEd	Math/Sci	Engr	TechElec	FreeElec	Total
Hope non-CHE	42	32	48	0	4	126
Hope CHE	42	47	48	0	0	137
Rose-Hulman	26.0	42.0	52.0	5.3	5.3	130.7
Cooper Union	24	54	48	9	0	135
Bucknell	24	40	64	4	4	136
Manhattan	27	45	59	0	0	131
Villanova	21	44	61	12	3	141
Minnesota-Duluth	19	52	55	3	0	129
Calvin	29	48	54	0	0	131
Widener	28	50	53	6	0	137
Michigan	16	46	56	0	10	128
Michigan State	22	47	49	0	10	128
Wayne State	29	49	58	0	0	136
Western Michigan	18	49	52	17	0	136
Michigan Tech	28	44	53	3	3	131
Averages						
Top 4 CHE	25.25	45.25	55.75	4.58	2.33	133.2
Other top 50 Engr	24.25	48.50	55.75	5.25	0.75	134.5
Other CHE in Mich	22.60	47.00	53.60	4.00	4.60	131.8

The 42 general education credits required at Hope are substantially higher than any of the benchmark schools, which fall in the range 16 to 29. Unlike many colleges and universities, Hope maintains requirements in diverse subject areas including foreign languages, fine arts, and cultural heritage. In math and natural science topics, the 48 credits required for the Hope chemical engineering emphasis fell near the middle of the comparison group. Note that the non-chemical emphasis students at Hope took only 32 credits in these topics since their chemistry requirement was completed by four credits of general chemistry. The 48 credits required at Hope in engineering topics is tied for the lowest among the comparison group schools. This met ABET distribution requirements.

Because of the high general elective credit hour requirements, the chemical emphasis at Hope did not include any elective courses, neither technical electives nor free electives.

Ten of the thirteen comparison schools included either or both types of elective among the credits in their chemical engineering programs. The total number of semester hours required for the program, 137, is near the top end of the comparison group but not extreme. About half the comparison schools required between 135 and 141 credits.

The challenge of fitting the chemical emphasis within the existing engineering program was accomplished by requiring three distinct sets of coursework as shown in Table 2.

Table 2. Coursework in Engineering and Chemistry Topics for the Chemical Emphasis Option.

Required Fundamental Engineering courses: (26 credits) ENGS 170: Computer Aided Design (1) ENGS 221: Introduction to Solid Mechanics (4) ENGS 222: Principles of Engineering Materials (3) ENGS 224: Mechanics of Materials Lab (1) ENGS 241: Electronics I (4) ENGS 331: Dynamic Systems and Controls I (3) ENGS 333: Dynamic Systems and Controls Lab (1) ENGS 345: Thermodynamics (3) ENGS 451: Introduction to Engineering Design (3) ENGS 452: Engineering Design (3) Elective Chemical Emphasis courses: (22 credits) ENGS 251: Conservation Laws & Process Calculations (4) ENGS 346: Fluid Mechanics (3) ENGS 348: Heat Transfer (3) ENGS 371: Chemical Reaction Engineering (3) ENGS 375: Advanced Thermodynamics and Separations I (4) ENGS 376: Phase Equilibrium and Separations II (3) The remaining two elective credits may be selected from other Engineering courses, or CSCI 160 or 225. Additional Chemistry courses: (17 credits) CHEM 114: General and Analytical Chem Lab II (1) CHEM 121: General Chemistry II (3) CHEM 221: Organic Chemistry I (3) CHEM 255: Organic Chemistry Lab I (2) CHEM 322: Inorganic Chemistry (3) CHEM 343: Physical Chemistry I (3) The remaining two Chemistry credits may be selected from lecture or laboratory courses at the 200 level or above.

26 of the 48 credits in engineering topics are common among all the emphasis options within the engineering program. All students in the program take these courses in common; there are not separate sections. In particular, chemical emphasis students do not have specialized process control, introductory thermodynamics, or design courses, but they take generalized controls, thermodynamics, and design courses with other engineering students.

The chemical engineering emphasis students receive their specialized coursework in the remaining 22 credits of engineering topics and 17 credits of additional chemistry courses. Before the chemical emphasis was offered at Hope, the only engineering topics courses offered from this list were the Fluid Mechanics and Heat Transfer courses. These were a required course and an elective course, respectively, for the mechanical emphasis option. Currently they are taken by both chemical and mechanical emphasis students. The four new engineering topics courses reflect typical chemical engineering educational practice with one exception. Advanced thermodynamics, mass transfer, and separations topics have been integrated into two courses. This is in contrast to standard practice where thermodynamics and mass transfer are taught as distinct courses.

The seventeen credits of additional chemistry courses, when added to the four credits of general chemistry required of all engineering students, also reflect the requirements for a chemistry minor at Hope College.

In 2003, in conjunction with the computer science department, the physics and engineering department designed and added to the catalog a computer emphasis option. It was based upon the existing electrical emphasis option with substitution of some computer science coursework. Following this approach, in 2004 a biochemical emphasis option was designed and added to the catalog. It consists of the same 48 credits of engineering topics courses with a distinct set of additional coursework in chemistry and biology, listed in Table 3, substituted for the courses listed in Table 2 for the chemical emphasis option. In 2008, a chemical engineering based environmental emphasis option was designed, using the coursework in Table 4. This option is expected to be added to the college catalog in 2009.

Table 3. Coursework in Chemistry and Biology Topics for the Biochemical Emphasis Option.

Additional Chemistry/Biology courses: (22 credits)
CHEM 114: General and Analytical Chem Lab II (1)
CHEM 121: General Chemistry II (3)
CHEM 221: Organic Chemistry I (3)
CHEM 231: Organic Chemistry II (3)
CHEM 255: Organic Chemistry Lab I (2)
CHEM 311: Biochemistry I (3)
CHEM 343: Physical Chemistry I (3)
BIOL 240: Cells and Genetics (4)

Table 4. Coursework in Chemistry and Geology/Environmental Science Topics for the Environmental Emphasis Option.

Additional Chemistry/Geology/Environmental Science courses: (19 credits)
CHEM 114: General and Analytical Chem Lab II (1)
CHEM 121: General Chemistry II (3)
CHEM 221: Organic Chemistry I (3)
CHEM 255: Organic Chemistry Lab I (2)
CHEM 343: Physical Chemistry I (3)
GES 211: Earth Environmental Systems I (3)
GES 430: Environmental Geochemistry (4) or GES 450: Hydrogeology (4)

Implementation of the Chemical Emphasis Option and Outcomes Before Graduation

Because of limited department resources, typically only one of the new chemical emphasis engineering topics courses is taught each semester. The three upper-level courses – Advanced Thermodynamics and Separations I, Phase Equilibrium and Separations II, and Chemical Reaction Engineering – are taught once every two years. These are taken by juniors and seniors concurrently. Conservation Principles and Process Calculations is taught each year in the spring, taken by freshmen and sophomore students in the chemical emphasis option and occasionally by upper level students in other emphasis options as an elective course. Table 4 shows a typical course sequence for chemical emphasis option coursework. To increase flexibility for student scheduling, ENGS 331, Dynamic Systems and Controls, has been offered during Hope College's May term in 2007 and 2008. About three-quarters of students in the chemical engineering emphasis option have chosen to take ENGS 331 at that time during the academic year.

Table 4. Typical Chemical Emphasis Option Sequence in Engineering and Chemistry Topics.

	Fall Semester	Spring Semester
Freshmen	Computer Aided Design General Chemistry I General Chemistry Lab I	Conservation Laws & Process Calcs
Sophomore	Introduction to Solid Mechanics Thermodynamics	Fluid Mechanics Heat Transfer General Chemistry II General and Analytical Chem Lab II
Junior	Electronics I *Advanced Thermodynamics and Sep I Organic Chemistry I Organic Chemistry Lab I	Principles of Engineering Materials Mechanics of Materials Lab *Phase Equilibrium and Separations II Inorganic Chemistry
Senior	Dynamic Systems and Controls I Dynamic Systems and Controls Lab Introduction to Engineering Design *Chemical Reaction Engineering Physical Chemistry	Engineering Design

*Taken in alternate year by students graduating in odd years.

Interest in the chemical emphasis option has grown steadily in the six years it has been offered. Table 5 gives data regarding the number of students selecting the option or taking Conservation Principles and Process Calculations as an engineering elective for a different emphasis option. Each entry in the table lists the number of chemical emphasis students at a certain level followed by the total number of engineering students at that level. It is difficult to provide precise counts of engineering students especially at the freshmen and sophomore level, because Hope students are not required to declare a major by a certain deadline in their careers as students. On the other hand, it is easy to count students interested in the chemical emphasis by enrollment in the Conservation Principles course. The data in Table 5 show that retention of chemical emphasis option students as they advance through the program has been excellent and significantly higher than overall retention of engineering students especially at the freshmen and sophomore levels.

Table 5. Student Enrollment in the Chemical Emphasis Option. First number is chemical emphasis students; second number is total engineering students.

Year	Freshmen	Sophomores	Juniors	Seniors	Total
2002-03	1/40	1/4	0/10	0/10	2/64
2003-04	3/42	2/20	1/4	0/10	6/76
2004-05	6/38	2/20	2/15	1/4	11/77
2005-06	2/40	5/32	2/15	2/15	11/102
2006-07	2/38	4/28	5/21	1/14	12/101
2007-08	9/43	0/26	4/23	5/21	18/113
2008-09		12/40	0/21	4/23	

Specifically, a total of 23 freshman students were enrolled in Conservation Principles over the six years from 2003 to 2008, plus one sophomore who took the course the first time it was offered in 2003. The number of students graduating in the option from 2005 to 2008, plus those continuing to make progress in the option in 2009, is 25. This indicates that the number of students who took Conservation Principles as freshmen but dropped out of the option were more than counterbalanced by students joining the option in their sophomore year, an apparent retention rate of greater than 100 percent. These numbers, not explicit in Table 5, total eight students who took Conservation Principles as freshmen but did not or are not completing the option, and nine students who joined the option during their sophomore year. All students who joined the option during the sophomore year have graduated with the option or are currently in progress. Table 6 summarizes these outcomes for students who showed interest in the chemical engineering emphasis option by taking Conservation Principles as freshmen or sophomores.

Table 6. Outcomes of Students Completing Conservation Principles by End of Sophomore Year.

	Enrolled in Course in 1st Year	Enrolled in Course in 2nd Year	Total
Graduated with Chem E emphasis option	5	4	9
2008-09 Senior in Chem E emphasis option	1	3	4
2008-09 Junior in Chem E emphasis option	0	0	0
2008-09 Sophomore in Chem E emphasis option	9	3	12
Graduated with other emphasis option in Engineering	2	0	2
Changed major out of Engineering	4	0	4
Left Hope College	2	0	2
Total	23	10	33

Students in the chemical emphasis option have the opportunity to participate in multidisciplinary experiences in their coursework, especially in the senior design classes. One recent design team consisted of three students who designed a mechanical feeder system with electronic controls for a chemical reactor at Pfizer, Inc. in Holland, Michigan. [3] Other design

teams including chemical engineers have worked on a sustainable water purification technology for a rural village in Cameroon [4], a test device for detecting gas leakage from defective automotive lamps, and the 2008 AIChE student design contest problem for conversion of coal to methanol. Other chemical emphasis students have designed a materials testing apparatus now used in the materials science laboratory, a shell and tube heat exchanger experiment and a pump and pipe rack system for fluid flow experimentation for the process laboratory, a bioreactor for water purification, a packed column hydraulics demonstration apparatus, and a small-scale alcohol fermentation demonstration.

One of the distinctive characteristics of Hope College is the opportunity for undergraduate research. Eight of the fourteen students who have reached junior status in the chemical engineering emphasis option so far did participate in a meaningful summer research experience (such as an NSF-REU program) no later than the summer following their sophomore year. Three others did so during the summer after their junior year. Three of the twelve current sophomores participated in such an experience during the summer following their freshman year.

Outcomes of Program Graduates

The first engineering student with a chemical emphasis option graduated in May, 2005. She also received a chemistry degree and participated in polymer chemistry research while at Hope. She is currently a Ph.D. candidate in materials engineering at the University of Illinois-Urbana-Champaign.

Two students graduated in 2006. Both participated in chemical property modeling research at Hope, both worked an engineering interns at local manufacturers, and they were coauthors of a student poster presentation given at the 2005 AIChE annual meeting. [5] One also coauthored an article which appeared in Chemical Engineering Progress [6] and he is currently completing an M.S. in chemical engineering at the University of Michigan. The second student also completed a DOE summer research internship studying membranes at Argonne National Laboratory in 2005. He is currently completing his masters degree at Ohio State University and recently took a job as a chemical engineer for an engineering firm in the Washington D.C. area.

One student graduated in 2007 and became the first program graduate to hire directly into an industry position. She is a chemical engineer with SmartSignal Corporation in the Chicago area. While at Hope, she participated in chemical property modeling research, worked as an intern for a local nuclear power electrical generating facility, and was a coauthor of a student poster presentation given at the 2005 AIChE annual meeting. [5]

Four students graduated in May, 2008 and one expects to graduate in December, 2008. All but one had received a job offer two months or more before his or her graduation. They currently work for ITT Space Science Division, the U.S. Department of the Interior, Huron Technologies, and Perrigo Corporation, with one graduate turning down several job offers to volunteer with the Peace Corps in the Dominican Republic. Four of these five students participated in undergraduate research at Hope College and two worked as engineering interns. Three of these students were coauthors of various posters and presentations given at

the 2006 and 2007 Michigan Space Grant Consortium (MSGC) Annual Conferences [7,8,9,10] and one received an undergraduate research fellowship from MSGC in 2006.

Conclusions

A chemical emphasis option was designed and implemented within the ABET accredited engineering program at Hope College. The emphasis option was successfully integrated into the existing engineering program coursework and also within the framework of a liberal arts college. Enrollment in the program and/or its courses has grown from 3 students in 2003 to 18 students in 2008 with high retention. Both chemical emphasis students and other engineering students have benefited from opportunities to participate in multidisciplinary experiences in coursework especially in design classes, and to participate in undergraduate research. Graduates of the program have had success in admission to high quality graduate degree programs and in finding chemical engineering positions in industry and government.

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