The Chemical Engineering Building (stone building on the left) and White Hall.

Chemical Engineering at . . .

Villanova University

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Villanova University

Villanova College was established in 1842 on the grounds of Belle Air, a 197-acre summer estate 12 miles to the west of Philadelphia. The property was purchased by the Augustinian order of priests and brothers with the intention of serving the educational needs of Catholic immigrants. In 1905 the School of Technology initiated a program in civil engineering. Other programs, including mechanical, electrical, sanitary, and chemical engineering, were added soon afterwards.[1] The chemical engineering program was instituted in 1919, and as early as 1943 there were 29 students in the graduating class.[2] To reflect growth in the number of academic programs, Villanova College was renamed Villanova University in 1953.[1] The program granted a Bachelor of Chemical Engineering degree through 2004 at which time the degree name was changed to Bachelor of Science in Chemical Engineering.

TABLE 1
Villanova Chemical Engineering Faculty, Educational Background, and Research Expertise

Faculty Member	Position	Doctoral Education	Joined Villanova	Expertise
Charles Coe	Associate Research Prof.	Carnegie Mellon University	2009	Zeolites, industrial catalysts, and adsorbents
Noelle Comolli	Associate Prof.	Drexel University	2008	Drug delivery, biomaterials
Jacob Elmer	Assistant Prof.	Ohio State University	2013	Gene therapy, blood substitutes
Jacky Huang	Associate Prof.	Texas A&M University	2011	Systems biology, microbial fuel cells
Scott Jackson	Adjunct Prof.	University of Delaware	2016	Process Design, undergraduate education
Donald Joye	Adjunct & Emeritus Prof.	Lehigh University	1981	Heat transfer, separations
William Kelly	Professor	Pennsylvania State University	1999	Upstream and downstream biopharmaceutical processing
Vito Punzi	Professor	Polytechnic Institute of NYU	1980	Industrial waste treatment processes, Catholic social thought
Rees Rankin	Assistant Prof.	Carnegie Mellon University	2013	Computational modeling, surface science
Edward Ritter	Associate Prof.	New Jersey Institute of Technology	1991	Kinetic modeling, reaction thermodynamics
Justinus Satrio	Associate Prof.	Iowa State University	2010	Biomass conversion, sustainability
Dorothy Skaf	Associate Prof.	University of Pennsylvania	1988	Photocatalysis, process design
Michael Smith	Associate Prof.	University of Delaware	2006	Catalysis, nanoporous materials
Peter Staffeld	Assistant Prof.	University of Pennsylvania	2009	Undergraduate education

Department of Chemical Engineering faculty as mentioned in Table 1. From left: Vito Punzi, Peter Staffeld, Justinus Satrio, Zuyi Huang, Michael Smith, Dorothy Skaf, William Kelly, Noelle Comolli, Edward Ritter, Rees Rankin, Jacob Elmer, Charles Coe, and Scott Jackson.

The original Chemical Engineering Building was built in 1947 and still houses the unit operations lab as well as some research labs and classrooms. The majority of chemical engineering activity takes place in White Hall, built in 1974 and named after Robert E. White, a long-serving chair of the department who was renowned for his high academic standards and commitment to alumni.

Although the exterior has changed little, the classrooms and labs have undergone several phases of renovation. A poignant landmark in White Hall is the third floor "graduation photo gallery" which displays graduation photos for all classes since 1951. White Hall also houses offices for 13 full-time chemical engineering faculty with a broad range of technical expertise, as shown in Table 1 on previous page. Expansion of the College of Engineering led to the construction of the Center for Engineering Education and Research (CEER) in 1997 with an expansion of CEER planned to begin in 2019.

Today Villanova University comprises a diverse learning environment dedicated to the Augustinian principles of veritas (the pursuit of truth), unitas (the fullness of community), and caritas (loving kindness). Villanova has approximately 6,000 full-time undergraduates, matriculated in four colleges: Business, Arts & Sciences, Engineering, and Nursing.

Junior chemical engineering students running experiments in the unit operations lab course.

TABLE 2
Statistics on recent chemical engineering graduates

Year	Number of ChE Graduates	% Female
2018 (anticipated)	69	44
2017	76	38
2016	48	44
2015	50	52
2014	33	29
2013	73	41
2012	50	37

The Engineering College offers five ABET accredited programs, including Chemical, Civil and Environmental, Computer, Electrical, and Mechanical Engineering, and accounts for approximately 1,000 undergraduate students. Inclusion of approximately 3,000 graduate students, a law school, and a school of professional studies gives a total university enrollment of approximately 10,000.[3]

THE UNDERGRADUATE CURRICULUM

The chemical engineering curriculum totals 129 credits including required humanities, science, math, and chemical engineering classes, as well as 47 credits of elective courses in these areas. With a strong liberal arts foundation, the curriculum provides opportunities for students to develop both the technical and non-technical knowledge and skills needed for success.

The freshman curriculum includes two three-credit classes, Engineering Interdisciplinary Projects I and II, intended to introduce students to engineering and to help them make an informed major selection. Each semester course is divided in half with the fall semester including a general overview of engineering and a themed project. Students select from among projects that are designed to be multidisciplinary, and each project has two instructors based in two different engineering departments. The projects address an engineering topic or issue and include rudimentary team-design projects. Recent project themes have included biofuels, cybersecurity, water treatment, structural design, dialysis, medical monitor design, robotics, and engineering in developing countries. The spring semester starts with a second themed project and finishes with an introduction course specific to the student's intended major. In 2014 Dr. Comolli redesigned the chemical engineering-specific portion of the class and used the chocolate manufacturing process as a means to introduce important chemical engineering concepts and unit operations.[4]

As experienced by many chemical engineering departments, recent class sizes have been large and more diverse compared to historical averages. Statistics on recent classes are provided in Table 2 and show that Villanova has consistently attracted a high percentage of female students into the program. Core chemical engineering classes start in the sophomore year and two sections of required lecture classes are offered to allow a lower student-to-faculty ratio in the classroom. Three or four sections of laboratory classes and senior design have been offered to accommodate limitations of experimental and computer facilities. Students start a three-semester lab progression in the junior year. The first class focuses on technical communications, the second introduces basic experiments with several unit operations and the third involves more complex experiments in which students are asked to address open-ended problems and plan their investigations. The unit operations lab reinforces concepts on distillation, absorption, and heat transfer, and complements lecture courses covering these topics.

The curriculum includes a sequence of technical courses that provide a theoretical basis and practical applications. Students can use chemical engineering, science, humanities, and free electives in the curriculum to pursue academic minors. In addition to traditional department-based minors, several interdepartmental minors are available to engineering students. One such minor is the bioengineering minor, which was created in response to faculty and local industry interest. Dr. Kelly led efforts to create the bioengineering minor, which was first awarded in 2012. This minor requires 27 credits including chemical engineering, engineering, advanced science, and ethics courses. In 2016 the minor was reorganized into three separate tracks, including biochemical engineering, bioengineering, and biomedical engineering minors to best serve students across the university. An interdisciplinary minor in engineering entrepreneurship was introduced in 2008 by the College of Engineering. This minor includes 16 course credits starting in the sophomore year, with courses emphasizing idea generation, consumer engagement, creating value, prototyping, and risk, while providing students the background knowledge to understand and interpret the business and financial aspects of a project. Many students pursue a business minor that can be earned within the academic year or through an intensive summer program. Student participation in minors over the last six years is summarized in Table 3 and demonstrates the degree of student interest in both technical and humanities areas.

The freshman year also includes a two-semester course sequence, the Augustinian Culture Seminars, which combines aspects of literature and writing classes in a small seminar classroom environment. The specific readings vary depending on the instructor, but are unified around themes related to Augustinian values. Other humanities requirements for chemical engineers include a specific requirement for an ethics course and options for values-related courses from a range of departments. Students also select two advanced science and four chemical engineering electives. The curriculum flexibility enables students to tailor their educational experiences to best meet their personal and career goals. As mentioned, many students use this flexibility to pursue minors, but others use it to build technical expertise or a broad educational foundation.

TABLE 3
Minors earned by chemical engineering graduates from 2012 through 2017

Minor	Total Students Receiving Minors 2012 – 2017
Business	52
Bioengineering	60
Engineering entrepreneurship	24
Chemistry	35
Other technical (biology, math, physics, computer science, etc.)	31
Humanities (language, philosophy, theology, peace & justice, etc.)	41

A graduate student and faculty member engage in research.

INNOVATIONS IN UNDERGRADUATE EDUCATION

The College of Engineering actively supports classroom and educational innovations. The civil engineering faculty were leaders in implementing an inverted classroom teaching approach that emphasizes content delivery outside the classroom, typically through recorded videos or audio-augmented PowerPoints, and content application during the scheduled classroom periods. This "flipping" of the traditional lecture approach enables active learning and greater student-faculty engagement in the classroom. Dr. Randy Weinstein (then department chair and currently the associate vice provost for teaching and learning) was the first chemical engineering faculty member to implement the inverted classroom approach for the course ChE 3131, Thermodynamics II. A publication on the classroom experience was recognized with the Corcoran Award presented annually for the most outstanding article published in *Chemical Engineering Education*.[5] A reported important component of the inverted classroom approach is students' accountability for their learning, which can be accessed through a short quiz administered at the beginning of the class period using course management software, such as Blackboard.

Most of the chemical engineering faculty use a hybrid approach in their classes, combining a variety of content delivery and classroom experiences. Audio-over software such as Camtasia® is used for screen recording and video editing to create supplemental course material, respond to common student questions, replace lectures while faculty are at a conference, and provide flexibility and depth to content delivery. This content has also been used to provide background content for chemical engineering electives to help address different levels of student technical preparedness and to provide instruction to all students on laboratory techniques or experiments that were too difficult or hazardous to perform in class. A team of four chemical engineering faculty have applied this logic to preparing students for bioengineering elective classes. They were recognized with the American Society for Engineering Education's (ASEE) Martin Award for Outstanding Chemical Engineering Paper for their presentation "Preparation of Biology Review and Virtual Experiment/Training Videos to Enhance Learning in Biochemical Engineering Courses," presented at the 2015 ASEE annual conference. Recent course innovations by Dr. Huang include the use of MATLAB in the process control course[6] and a control demonstration based on heating and cooling of a metal bar, developed by Dr. Huang and Dr. Ritter. Other approaches used in the classroom include team design projects, impromptu in-class assignments, and industry-sponsored real-world problems.

The College of Engineering has been a member of the Kern Entrepreneurial Engineering Network (KEEN), since 2007 and has been promoting entrepreneurial skills among our students not only through the engineering entrepreneurship minor, but also through incorporation of experiences that promote entrepreneurial thinking into core and elective classes. Through a KEEN grant, the College supports a "Keen Champion" in each engineering department to enhance faculty efforts to incorporate entrepreneurial activities within departmental courses. Dr. Comolli has been working to identify these opportunities across the chemical engineering curriculum. Existing design projects have been modified to include features such as market analysis and cost estimation. In the Fall 2016 semester, a KEEN e-learning module developed by University of New Haven faculty was incorporated into ChE 4131, Process Design I. The module content was used to encourage students to apply a systems-thinking mindset to identify a globally optimal process design. A Villanova Institutional KEEN grant also provides college-wide opportunities for students to develop idea generation skills and identify value-creation skills.

Faculty continue to develop innovative teaching approaches and electives options and a few examples are highlighted here. In 2010 Dr. Kelly joined with a business faculty member, Dr. Jonathan Doh, to create a new course, ChE 2900 Global Pharmaceutical Industry. This class enrolls business students and engineering students and introduces both to the technical and business basics of the pharmaceutical industry. Students are also introduced to new technologies, regulatory requirements, supply chain management concepts, and issues of global access to medicine. Dr. Punzi created the course ChE 2930, Catholic Social Teaching for Engineers, to address student interest in this topic. This seminar-style course is open to all engineering majors and reviews key themes in Catholic social teaching. In the course, students address how engineers can apply these principles at various stages of their careers to develop engineering solutions that promote the common good. Finally, in spring 2016 Dr. Smith used the beer brewing process as an overarching theme in ChE 5132, Transport Phenomena, as a way to enhance student interest in the topic. The overwhelmingly positive student response led Dr. Smith to create a popular new technical elective entitled "Introduction to Brewing Science and Technology," which covers the science, processing, and business aspects of brewing beer.

Curricular improvements are also driven by College of Engineering efforts. For many years engineering students were required to participate in extracurricular professional development activities. To help guide these experiences into a more coherent educational component for students, the Career Compass program was initiated in 2016. The program was designed with guidance from an industrial advisory board and includes educational experiences such as recorded lectures, live presentations, and professional mentors. It is integrated across the first three years of the program with elective participation in the fourth year. The topics include career-building skills such as time management, leadership, communication, and engineering ethics. The program creator and coordinator, Professor Frank Falcone, is a full-time College of Engineering faculty member and the program is supported by alumni endowment and industry contributions.

The Chemical Engineering Department also benefits from a vibrant College of Engineering service-learning program. More than half of engineering undergraduates are involved in a service-learning project during their time at Villanova. Opportunities include a freshman mini-project on engineering in developing countries, educational outreach activities, STEM outreach activities through professional societies and Villanova clubs, campus ministry, and service-learning trips to rural communities.

Chemical engineering students actively participate in study-abroad programs administered by the Office of Education Abroad. Options for study abroad during the normal academic year have been focused in the sophomore spring semester. Students have attended schools in England, Wales, Italy, Spain, and Australia. One notable program is offered through Arcadia University at Roma Tre University in Rome. At Roma Tre, students take two core chemical engineering courses, a required introductory class on the Italian language, and one or two electives. Between 2016 and 2017, 22 sophomores attended the Roma Tre program. Summer study-abroad programs provide many flexible opportunities for students to study overseas, and participating students typically earn credit for two humanities electives from these programs.

GROWTH IN GRADUATE PROGRAMS

The Chemical Engineering Department has introduced new graduate-degree programs to support faculty and college interests as well as the needs of working professionals. A Master's in Chemical Engineering degree program (MSChem) was initiated in approximately the late 1950s. The MSChem program currently enrolls about 40 students with historically 75 - 80% part-time students. The MSChem program was the only graduate program until 2013, when Dr. William Kelly led efforts to create the program for a Master's in Biochemical Engineering (MSBioChem). The new master's degree program serves the needs of engineers working in local pharmaceutical and biotechnology companies. The MSBioChem program has grown rapidly and currently enrolls nearly 30 students with approximately two-thirds being working professionals. The MSBioChem program has successfully transitioned non-chemical engineering undergraduates into the engineering graduate program.

To support growth in research and driven by faculty interest, the College of Engineering initiated a doctoral program in engineering in Fall 2003. Since then, three chemical engineering students mentored by Drs. Satrio, Kelly, and Huang have earned doctoral degrees. The doctoral program includes primarily full-time students but offers a part-time option for working professionals. In Fall 2017 there were 11 matriculated doctoral students, and faculty continue to support growth of the degree program. In 2016, core curriculum revisions in all graduate programs were instituted to provide better integration between the programs and promote critical competencies of the graduates from all programs.

The Chemical Engineering Department is committed to providing quality graduate programs. Most classes are taught by full-time faculty with industry experts providing needed expertise for specific courses. All engineering master's degrees can be earned by traditional attendance in lectures or through distance learning options. A unique feature of graduate courses is that the class meets as a traditional lecture while being live-streamed, and the archived lecture is made available to all enrolled students. The technology allows innovative inclusion of distance students in classroom discussions and lecture presentations. The distance education option often provides working professionals needed flexibility to continue their education despite conflicts with work hours or travel. The archived lectures for a course are available to all enrolled students for several years after the initial recording. The College of Engineering supports full-time staff in an Engineering Distance Education Center and has outfitted recording hardware in numerous classrooms. The Distance Education Center provides technical support for all distance-learning graduate classes. The center resources are also provided to faculty teaching undergraduate classes and have been used to record lectures for an inverted classroom experience or to create videotaped lectures for use while faculty attend professional conferences.

Growth in the College of Engineering's doctoral program and other doctoral programs across the university has led to Villanova's reclassification in 2016 as a Doctoral/Research University within the Carnegie Classification System. As expressed in Villanova University's 2010 strategic plan, the institution is committed to enhancing its national stature and demonstrating the complementary role of research in educational excellence. The university has responded to the challenges with a "feed forward system" of financial and infrastructure changes to support research and ensure continued success through this transition. Generous alumni support has been an essential component of this research expansion.

FACULTY RESEARCH AND PROFESSIONAL LEADERSHIP

The chemical engineering faculty pursue a teacher-scholar model in which both teaching and research are important components of their careers. Recent growth in the undergraduate and graduate programs has complemented increased faculty research and brings students into direct contact with recognized technical experts.

Undergraduates contribute to ongoing faculty research as volunteers, work study students, summer scholars, university-sponsored scholars, and students in a senior two-course sequence. The Chemical Engineering Department benefits from an alumni endowment that annually provides funds for eight to 10 undergraduates to participate in summer research. The university and college run several grant programs for summer research that range from student-initiated project ideas

to faculty-mentored scientific proposals. The senior research class option requires a two-semester commitment and is pursued by approximately one-third of the senior class. Undergraduates typically join in team projects to support ongoing faculty research. With the comparatively small size of the graduate program, undergraduates often make significant contributions to research and are included as co-authors on publications. Recent undergraduate research projects have included microbial fuel cell scale up, non-viral gene therapy, invertebrate hemoglobin as a blood substitute, fast pyrolysis of biomass for fuels and chemical feedstocks, computational chemistry for catalyst screening, and sorption-enhanced hydrogen production.

A senior student contributes to a research project as part of the research course elective.

Faculty research efforts are being recognized through increased grant awards to support their research. Drs. Kelly and Coe have successful track records of industrial research support. Dr. Rankin has supported his computational chemistry research through several grants for supercomputing time. Drs. Satrio and Coe participate in a Department of Energy consortium to research on-farm production of biofuels. Since 2015 Dr. Elmer has been collaborating on an NSF grant with Arizona State University faculty to investigate how cells regulate foreign genes. In 2016 Drs. Elmer, Comolli, and Kelly collaborated on a successful NSF EAGER Grant to optimize the transfection of T cells. Dr. Elmer received a 2017 NSF CAREER Award to support his investigations of the innate immune response to gene therapy and a 2017 NIH grant to continue investigation of earthworm hemoglobin as a blood substitute and *in vivo* testing. This momentum in research is fueling growth in the graduate programs and continues to bring new educational and research opportunities for undergraduates.

Several faculty hold leadership positions in internationally recognized organizations. Dr. Kelly is an invited member of the European Society of Biochemical Engineering's Scientific Committee and an elected member of the ACS Biotechnology Division Executive Board. Dr. Huang has served on the International Federation of Automatic Control Policy Committee. Dr. Satrio is helping to found an Indonesia-USA collaboration focused on the sustainable development of oil palm biomass for energy and chemicals.

THE FUTURE OF THE DEPARTMENT

The Chemical Engineering Department faces a strong future as it pursues the university and college vision of growth in research and graduate programs balanced by a continued commitment to excellence in undergraduate education. The department is poised to meet future challenges as well as harness future opportunities to continue to meet the needs of its students and advance the profession.

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