Development and implementation of an integrative engineering program at Lafayette College

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Work-in-Progress: Development and implementation of an integrative engineering program at Lafayette College

Abstract

We describe the impetus for and collaborative process used to develop a cross-disciplinary B.S. engineering program with a systems thinking core and focus areas in bioengineering, environment & energy, and robotics. Lafayette College is an undergraduate only liberal arts college with long-standing accredited B.S. degrees in chemical, civil, mechanical, and electrical & computer engineering, as well as a A.B. degree program in engineering studies. An internal visioning review of engineering at the college in 2005-06, a college-wide strategic plan completed in 2007, and then an external review of the engineering division in 2011 all recommended that additional structures be developed to encourage cross-disciplinary areas of study within engineering and to better integrate engineering with the liberal arts environment of the college. However, other priorities, a reduction in total courses from 38 to 36, and a general lack of support from engineering faculty for new programs led to inaction on major curricular change until the past three years. A new administration and strategic growth plan adopted by the college in 2016 provided a renewed opportunity to consider how the engineering division might respond to some of the recommendations of the earlier reviews. In this paper we describe the lengthy process of development of the program and challenges along the way. As the program was just launched in Fall 2019, we do not present assessment data here, but rather briefly describe our approach to program assessment.

Introduction

The 2016-17 academic year marked the 150th anniversary of engineering degree programs at Lafayette College is a liberal arts college of ~2600 undergraduate students in Easton, PA. At the March 1866 board of trustees meeting the college had instituted its first engineering degrees in civil and mining engineering, citing "a demand to set the goal of educating not just the engineer, but the 'whole [person]' who is able to meet the challenges of a world in which, scientific, technological and human needs have steadily become more complex [1]." This same statement could have been written 100 years later in 1966 or in 2020.

The practice of engineering and likewise academic programs in engineering at Lafayette has changed greatly since 1866: electrical engineering (now electrical and computer engineering, but then part of physics department) was started in 1890, mechanical engineering in 1912, and chemical engineering in 1915. Former degree programs in mining engineering, industrial engineering, and metallurgical engineering no longer exist. An A.B. engineering degree (now the Engineering Studies program) was created in 1970 as a bridge between engineering and the liberal arts. This program was intentionally designed to "educate sociotechnical, integrated,

technological citizens [2].” With four independent B.S. departments and one A.B. program, the engineering division is a significant component of the college, both in terms of academic offerings and associated resources. Indeed, approximately ¼ of the Lafayette student body has one of the five majors within in the Engineering Division and currently 40 out of 228 total full-time tenured or tenure-track faculty at the college are housed in engineering.

The existence of discipline specific engineering degree programs at a small liberal arts college is unusual, presenting both opportunities and some significant challenges to curricular innovation. As recently as 2011, engineering at the college was characterized as “offering primarily traditional engineering degrees, through curricula that appear at least as restrictive as those at some traditional engineering schools [3].” This paper focuses on the development of a new integrative engineering degree program at the college that was launched in 2019 as a means to increase cross-disciplinary engineering opportunities for students and faculty. We first describe the long process that led to the program and challenges faced along the way. Although this story is necessarily specific to Lafayette and its particular governance structures, it is important to include to provide context about the program and how it fits with the existing engineering degree programs. We then describe the program itself and plans for future assessment.

Organizational structure and leadership of engineering at Lafayette

In the typical small liberal arts integrated college model, Lafayette does not have a dean nor autonomous school of engineering. Instead, a Director of Engineering oversees the division, and Engineering Council, consisting of the department (4) and program (1) chairs and chaired by the Director, serves as an informal coordinating body between the four B.S. departments and the A.B. Engineering Studies program, however it is not empowered to enact curricular changes. Each department/program operates independently, and curricular changes are proposed by each degree program through the college-wide Curriculum and Educational Policy Committee and must be approved by the full faculty of the college. There is course sharing and coordination within the lower level engineering science (ES) courses and a common first year introductory engineering course (ES 101), but little interaction between the degree programs once students enter the junior year. Perhaps because of this long history of successful independent disciplinary engineering programs and the structural boundaries to enacting major changes, curricular innovation and cross-disciplinary interaction within the B.S. engineering programs, or between those programs and Engineering Studies has been limited over the past 20 years, mostly occurring at the individual faculty collaboration level. This is not to say that there have not been efforts towards a more unified approach to curricular change, as described in the next section.

Recent history of strategic planning and curricular changes

Starting in 2005, with a new President at the college, and the recent publication of NAE’s *The Engineer of 2020* [4], the engineering division embarked on an internal strategic planning exercise. A committee of seven engineering faculty representing each of the engineering programs addressed the following questions: Where are we now? Where do we want to be? How will we get there? [5] A new mission statement was adopted by the division as part of the review:

> "The mission of the Engineering Division of Lafayette is to be a leader in undergraduate engineering education. The Division will provide an environment that fosters the student-centered educational goals and mission of the College. The engineering programs will be known for their quality and the accomplishments of their students, alumni, and faculty."

The following strategic initiatives were identified in the draft report:

- Creating a structure for strong divisional leadership
- Revising the faculty reward system
- *Enabling flexibility in engineering curriculum* [emphasis added]
- Increasing national recognition
- Increasing interactions between the division and alumni
- *Leveraging the uniqueness of engineering in a liberal arts environment* [emphasis added]
- Increasing diversity
- Broadening and supporting scholarship

However, this internal effort was never completed nor formally introduced to the administration because, at the same time, a college-wide strategic planning exercise was occurring with formally appointed ad-hoc committees working on various components of the plan. The relevant committee to curriculum was the "Curriculum Subcommittee of the Strategic Plan Steering Committee" (SPSCC), which included three faculty members from engineering. This small group of faculty was keenly aware of the conclusions of *The Engineer of 2020*, in particular the aspiration (p. 50) "We aspire to an engineering profession that will rapidly embrace the potentialities offered by creativity, invention, and cross-disciplinary fertilization to create and accommodate new fields of endeavor, including those that require openness to interdisciplinary efforts with nonengineering disciplines such as science, social science, and business."

This committee produced a *Report of the SPSCC on the Program, Curricula, and Curricular Role of Engineering at Lafayette College* containing a number of recommendations, including (paraphrased here for brevity):

- *Increase the cross-disciplinary efforts within engineering to enhance existing programs, create greater flexibility within them, and make efficient use of the talents of faculty and staff* [emphasis added]
- *Increase the number of free electives in the B.S. engineering curricula to enable students to benefit more fully from the liberal arts* [emphasis added]
- Facilitate communication between faculty across campus about engineering
- Take steps to increase the profile and improve the standing of the A.B. engineering program
- *Consider addition of a general B.S. program in engineering* [emphasis added]

These specific recommendations did not make it into the new administration's final "Plan for Lafayette 2007". However, the plan did include the following two components relevant to engineering:

"Education for the built environment. With its unusual combination of liberal-arts offerings, an A.B. engineering major, and discipline-specific B.S. engineering programs, Lafayette is

exceptionally well positioned to achieve leadership among highly selective small colleges in broadening each student's education and fostering engineering and technological literacy. The College can strengthen the integration of the Engineering Division's offerings into the educational experience of non-engineering students and of liberal-arts programming into the experience of engineering majors. New courses can be developed to help all students more fully understand the social, historical, political, moral, and aesthetic implications of engineering practice and accomplishment. Special emphasis will be placed on increasing the profile and standing of the A.B. engineering program as a bridge between the Engineering Division and the liberal arts."

"Education for environmental understanding and action. Building on the existing interdisciplinary environmental science minor, on faculty strengths in all academic divisions of the College, and on the campus community's interest in being more environmentally engaged, Lafayette will increase its commitment to the study of the natural environment, environmental issues, and environmental policies. Specific steps to be considered include adopting a new B.S. environmental sciences and engineering major and a new A.B. major in environmental studies; adding faculty in appropriate areas throughout the divisions of the College to support the program; and adding an introductory course in environmental science and a capstone project course."

These two components of the 2007 Plan both emphasize the integration of engineering with the liberal arts and cross-disciplinary approaches. In the following years the AB Engineering Studies program did gain a new faculty line, and a new degree program in Environmental Science and Studies (but not engineering) was launched and was allocated one faculty position, later adding a second position.

In 2010 the President and Provost requested a comprehensive external review of the engineering division, which occurred in March 2011. The review report [3] made numerous observations and recommendations regarding strengths and weaknesses, including the following:

> "the lack of opportunity to pursue program tracks or focus areas, particularly in biotechnology, sustainability, or engineering systems. We would recommend that the faculty consider ways to meet this interest, perhaps by incorporation of biology as a preferred elective into the science curriculum, and developing interdisciplinary engineering focus areas around topics such as biotechnology or systems engineering."

Following receipt of the review report, the engineering division launched into a visioning process that included a number of meetings, study groups, and a summer retreat off campus. In fall 2011 the division was directed by the Provost to decrease total course requirements to 36 (from 38), with no more than 26 STEM courses, and with increased curricular connections within engineering. All B.S. programs revamped their curricula to comply with this directive; however, there was little remaining enthusiasm for developing new interdisciplinary focus areas or programs.

In 2013, a new President was hired at the college and a new 10-year strategic plan was launched in 2016, which calls for increasing the size of the college by approximately 400 students and 40

new faculty. This growth plan provided additional impetus to the engineering division to reconsider some of the recommendations of the 2011 review and its earlier visioning work. A retreat was held in August 2016 to discuss the possibilities afforded by growth. Particular concerns voiced were the effect of student body growth on pedagogy, the ability to deliver quality student-focused programs, and practical resource issues (both space and budgetary). Some growth was in fact already occurring (see Figure 1) and causing serious enrollment pressures, especially in mechanical engineering. To some extent these trends mirror national increasing trends in undergraduate engineering degrees granted, particularly in ChE and ME [6]. Two degree programs were often at the threshold of having to split second lecture sections and add third lab sections. Following the retreat, Engineering Council developed several tasks and appointed working groups, including in particular an "Interdisciplinary Themes Task Group", as described below.

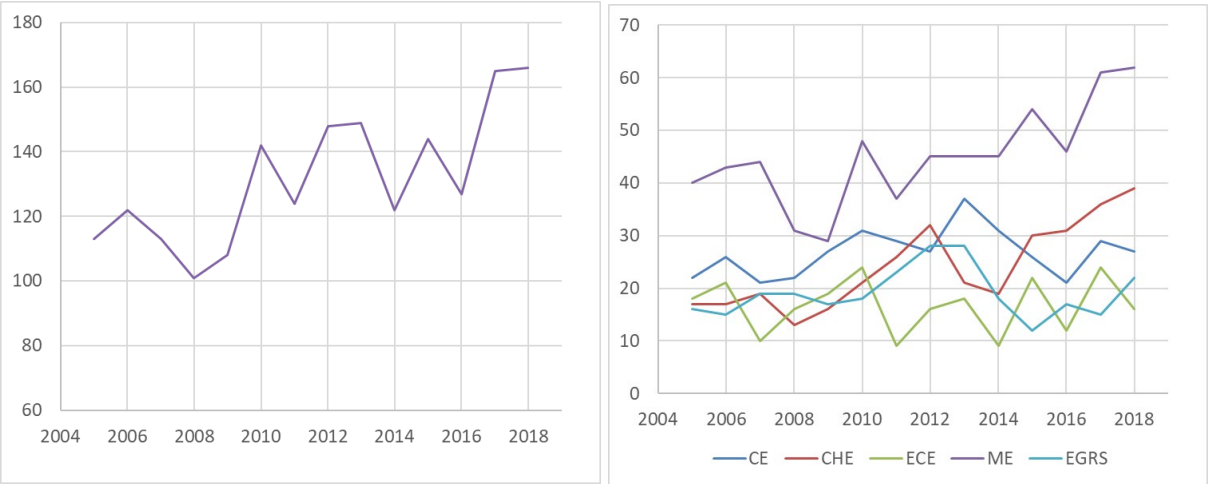

Figure 1. Growth in number of engineering graduates (total for all five degree programs) and by degree program. CE = Civil Engineering, ChE = Chemical Engineering, ECE = Electrical and Computer Engineering, ME = Mechanical Engineering, EGRS = Engineering Studies

Moving forward: the Interdisciplinary Themes Task Group

The Interdisciplinary Themes Task Group (ITTG) was charged in fall 2016 with developing flexible curricular models/options that could support interdisciplinary themes such as bioengineering, environmental, energy, entrepreneurship, robotics, materials, etc. Such themes were imagined to build on existing faculty and curricular strengths and connect to related programs in the liberal arts. For example faculty in both CE and ChE were teaching and conducting research in the area of environmental engineering, yet engineering students were not benefitting from both sets of expertise. It was not intended that any new programs developed would replace or impact the integrity or quality of the existing five departments and programs.

The initial task group consisted of two senior faculty co-chairs (from CE and ChE), three additional tenured faculty, three pre-tenure faculty, and the Director of Engineering as *ex officio*. Early on, the group established a list of criteria (goals, strategic objectives, and current needs) that any curricular recommendation would need to satisfy:

- provide students with increased opportunities to study and work in interdisciplinary areas of engineering,
- increase interdisciplinary interaction among students,
- provide students in existing programs with opportunities to take a wider array of elective courses,
- enable existing and new faculty the opportunity to offer an increased number of electives to support their programs,
- attract more top students by offering areas of engineering study not currently available at Lafayette
- provide a flexible framework that enables new interdisciplinary clusters to be developed and old ones to be phased out as technologies shift,
- increase the ability of the College and existing programs to manage enrollment within engineering,
- retain the distinctiveness, rigor, and close student/faculty interactions of the degree programs, and
- increase the attractiveness of the engineering programs to students from underrepresented groups.

The group met every two weeks and developed a draft white paper that explored four options:

1. Add new accredited BS degree programs in interdisciplinary areas of engineering
2. Modify existing BS degree programs to make room for interdisciplinary themes
3. Change nothing and continue to offer existing programs as they currently stand
4. Add an accredited BS engineering degree with focus areas in interdisciplinary fields

After extensive research and discussion, the first three options were deemed nonviable to the task group. Adding a new separate degree program would likely result in an additional silo rather than increase interaction between the existing programs, and would likely not survive the scrutiny of the full faculty, many of whom are opposed to adding new programs or growing the size of the engineering division. Further, we might then actually need a new program for each cross-disciplinary area, a highly inefficient way forward. In the case of the second option, carving out curricular space from the existing programs, for example by adding tracks or themes, would likely impact their integrity and was counter to the broad-based approach of the existing degree programs. Also given that the imagined themes were cross-disciplinary, it would be philosophically untenable for them to be housed within a disciplinary department (would one put robotics in electrical or mechanical engineering?). The third option, to change nothing, would mean that interdisciplinary engineering curricula and collaboration were effectively dead, an outcome that none of the committee would accept. Only the final option, adding a new BS degree program with cross-disciplinary focus areas was deemed worthy of additional analysis.

This white paper with the detailed analysis done by the committee was presented to the engineering division at an August 2017 retreat, resulting in a fairly lukewarm reception. Part of this response was due to the fact that some faculty had no interest in cross-disciplinary teaching and research, many had not participated in the process nor the previous reviews (we heard the question “What problem are we trying to address”?), and many had concerns about resources and how the existing departments would be impacted. Another major concern was how the program

would be distinct from the A.B. Engineering Studies program, which is highly interdisciplinary with the liberal arts (19 required STEM courses vs. 26 for the B.S. engineering degrees). The consensus was that additional work was needed to consider more fully how any such program would be structured and the implications to existing programs and resources.

Undeterred, the task group went back to work the following academic year (2017-18), with the same co-chairs but also adding many new members – essentially anyone interested in contributing, including many untenured faculty. The group held weekly open lunchtime meetings with all minutes and materials placed on a shared drive accessible by all engineering faculty. Periodic engineering division meetings were held to update the community at large. These weekly meetings developed a spirit of collaboration and openness that greatly benefitted the effort. The goal of this reconstituted task group was to develop a detailed proposal that would address the concerns identified in the retreat as well as others that came up during the course of the year. Because any new program would impact the existing engineering programs, it was recognized that any formal proposal from the division would need to have the support of the majority of the division faculty.

While the task group focused primarily on curriculum, the Director of Engineering developed a detailed resource model considering growth of the college and assuming that approximately ¼ of the new students would be in engineering, and that the existing 16:1 student:faculty ratio in engineering would remain a constant (i.e., an expectation of ~6 new faculty in engineering). The model looked at the implications of simply growing the existing programs proportionally vs. growth with a new cross-disciplinary program that would absorb some of the new students. The conclusion of the resource model was that the new program would have some advantages in terms of resources because of a "load-leveling" effect, given that students in the program would be taking courses spread across the existing programs and from other degree programs outside of engineering. This result was in part due to two of the existing B.S. programs (CE and ChE) being near the threshold of having to split lectures and add lab sections, which comes at a high resource cost in faculty teaching loads. Depending on the size of the new program, the frequency of that happening was lessened. This resource modeling process was iterative since the details of the proposed curriculum obviously impacted the model results. The task group found that the quantitative model was an important step in hypothesis testing and helped in confidence and consensus building due to its transparency.

The proposed program

The work of the expanded task group continued through August 2018, during which time the group developed a proposal to offer an ABET-accredited BS engineering program with cross-disciplinary themes or focus areas. The 45-page document included contributions of over 30 faculty and staff across all of the engineering programs, a significant accomplishment of collaboration in itself.

The task group agreed that rather than simply being a collection of courses drawn from existing programs, the new program needed a core to provide the context and theoretical framing for the cross-disciplinarity approach. A systems thinking [7] core sequence of three courses was included to provide a common language for students to encourage thinking across disciplinary

boundaries and to see connections or analogies across fields. To encourage students to also consider the human dimension of engineering design, the engineering studies course "Engineering and Public Policy" would be an essential part of the systems core.

The group settled on three focus areas: bioengineering, environment and energy, and robotics, but recognized that others could be added (or deleted) in the future. These three areas were selected based on existing faculty expertise, but also on past student demand and on national trends in enrollment [6]. The program would be distinct from interdisciplinary A.B. Engineering Studies program in that the degree is an engineering degree with the same math and science requirements and number of courses (36) as the other B.S. engineering programs, and the three themes are primarily cross-disciplinary *within* engineering. There would however be two related courses (chosen from an approved list) for each theme that would count for the degree program and could come from outside the engineering division, establishing an intentional link between the theme and similar subjects in the liberal arts. This also meant that two of the required 26 courses for the engineering degree could be taken outside of engineering, a departure from the four existing B.S. engineering programs. Of course this generated some pushback regarding whether the program would be seen as "engineering-lite."

The 26-course program is summarized below (new courses with asterisk):

Math and Science Core (8 courses):
o MATH 161 Calculus I
o MATH 162 Calculus II
o MATH 263 Calculus III
o MATH 264 Differential Equations
o PHYS 131 Physics I or PHYS 151 Adv. Physics I
o CHEM 121 Gen. Chem I
o ES 231 Nature of Materials or ES 232 Biomaterial Science
o Science elective

Systems Core (5 courses):
o ES 101 Introduction to Engineering
o *ES 103 Systems I
o *ES 201 Systems II
o CS 104, 105, or 106 Computer Programming
o EGRS 251 Introduction to Engineering and Public Policy

Thematic Concentration (11 courses):
o *ES 301, 302, or 303 Systems III (one for each focus area)
o five engineering electives (from approved list)
o three STEM electives (from approved list)
o two electives related to the theme from any division of the college (from approved list)

Capstone design (2 course sequence)

Formal approval of the program

As described above, college governance requires that new programs be approved by the college-wide Curriculum and Education Policy Committee and a vote of the full faculty. Because a proposal for a new engineering program would come from the engineering division at large, the task group needed to have the support of the majority of division faculty. The task group placed the final 45-page program proposal on a shared drive for open review by the engineering faculty two weeks prior to the division retreat. Then, in mid-August 2018, the proposal was presented to the entire engineering division at the retreat. The long process of arriving at the proposal was reiterated, in particular focusing on the collaborative spirit that had developed along the way and the number of pre-tenure faculty that were enthusiastic about the new program. Although some concerns remained regarding resources and staffing, overall the faculty attending the meeting were supportive. At the end of the month, a vote was taken using the following online anonymous survey:

> "1) Do you support the engineering faculty crafting and submitting a proposal to CEP to offer a Bachelor of Science in Engineering (BSE) degree program? The CEP proposal will be based on the document that was written in preparation for the recent engineering retreat and will be written using a similar process of an engineering-wide collaboration using a shared Google Doc. (Answer yes or no)
>
> 2) I am committed to making the BSE program a success. (answer using a 5-point Likert scale)
>
> 3) Please provide additional comments below."

The results were highly supportive: 37 of 39 engineering faculty voted, and 31 were in favor of moving forward with a formal proposal. Of these 37, 16 were strongly committed and 11 were committed to making the program a success. With these results the task group then was empowered to draft a proposal to CEP, and began meeting with outside programs that could be impacted by the new degree program. In particular the Head of the Biology Department was contacted, as many courses that might be taken by students in the bioengineering theme were in biology. Letters of support for the proposal were obtained from the Provost (regarding resources), the Head of Biology, and the Chair of Environmental Science and Studies. The proposal came to the full faculty for a vote in December 2018. However, at the same meeting, a vote was held regarding the college-wide academic plan for growth that would dictate the direction of some of the new hires into six particular focus areas, which did not include engineering. Unfortunately these circumstances, and the general suspicion that engineering was up to some kind of resource grab and had not done enough assessment of external impacts were too much to overcome, and the vote failed by a close margin.

The following spring (2019) the co-chairs worked extensively to hold campus-wide open meetings, small focus groups, and a series of meetings specifically with the Biology Department about how to address their concerns regarding enrollment pressure from engineering. These meetings resulted in some new additions to the proposal, as well as a refinement of courses on the approved course lists for each theme. For example, the revised proposal included a more

extensive discussion of inclusive STEM issues in engineering and how the new program might play a leadership role in more proactively tracking and responding to issues. Also included in the revised proposal was a course in Systems for Non-Engineers that would contribute to the college-wide common course of study. The revised proposal was then put before the faculty in May 2019. The final faculty vote was 91–19 in favor, a relief to all involved and in particular the co-chairs that had now spent three years carrying the idea forward. The program was enthusiastically approved by the Board of Trustees a few weeks later.

Program Implementation

We are now in the process of implementing the new program. A program chair was selected in summer 2019 and then an advisory committee was appointed by the Provost with representation from each engineering program and an outside member from the biology department. One of the first accomplishments of the committee was to draft and adopt the following mission statement:

> "The Bachelor of Science in Engineering program provides an integrative engineering curriculum grounded in a systems perspective. Complex systems are analyzed and modeled using an approach highlighting the commonalities between systems across various fields of study. The program provides students with the opportunity to develop systems thinking and to study in emerging and interdisciplinary fields of engineering. Graduates will be distinguished by their broad understanding of design and systems thinking and by their ability to communicate across engineering disciplines and related fields of science."

Because the program was not approved until May 2019, it was too late to recruit incoming students to the program for the current academic year; however, during the fall semester several information sessions were held for first-year engineering students and a FAQ document was developed about the program. In addition, a website was developed (bse.lafayette.edu) and the program is featured on the engineering division website. As a result of these initial launch efforts, approximately 13 students signed up for ES 103 Systems I in spring 2020, and these students now form the first program cohort. Over the next two years, we will begin offering the core sequence: Systems II in fall 2020, and Systems III (three different courses, one for each focus area) in fall 2021. Initially we will rely on capstone courses in the existing engineering programs but eventually will develop our own capstone course as staffing allows.

Staffing the program with tenured and tenure-track faculty is anticipated to take at least 5 years. Staffing will occur through a MOU with existing faculty (recognizing of course that most of the engineering programs are already feeling the pinch of increased enrollments) or new hires with joint appointments with the other engineering programs. All such hiring is through the usual college channels, the staffing advisory committee of the Faculty Academic Policy committee. As resources are scarce and the process is highly competitive, it remains to be seen how rapidly the new program will be able to staff up. Cooperation between the programs in developing staffing proposals will be important so that needs are met equitably. We are hopeful that the open and collaborative process that resulted in strong support of the new program by most the engineering faculty will translate to a collaborative effort in hiring new faculty through joint appointments.

At the time of this writing we are planning to name the program “Integrative Engineering.” This choice is inspired in part by the field of Integrative Biology, which is generally defined [8] as a field that "bridges disciplines, and it works within and across levels of biological organization and across diverse taxa over time, short (ecological or physiological) and long (evolutionary)." A recent joint report by the National Academies of Science, Engineering, and Medicine [9] has “integration” as its central theme and encourages an approach in which “professors help students understand the connections among the disciplines.” Our program has many of these same discipline-bridging, multiscale characteristics in that we are adopting a systems framework to encourage students to see connections across the traditional engineering disciplines and to view their degrees and expertise within a larger scientific and social context.

Assessment and accreditation

An assessment plan is under development by the chair and advisory committee. Areas planned for assessment include: enrollment, retention, and impact on enrollments of the other engineering programs and individual courses; diversity and numbers of under-represented groups as compared to the other engineering programs; staffing and resources; mission, program educational objectives, and student learning outcomes; and curriculum. Once the program begins to graduate majors an important assessment metric will be placement of graduates in industry jobs and graduate school.

The program will be accredited under the ABET’s General Criteria. The General Criteria have the same student outcomes (1-7 in the new ABET) as all B.S. engineering programs but there are no program-specific criteria. Student outcomes will be assessed using similar methods as the existing BS programs at the college, but it is recognized that this will be more challenging for an interdisciplinary program where students take many of their courses from various other departments and programs. The core sequence and capstone will be relied upon heavily for assessment activities. The spring 2020 cohort will graduate in 2023, and the following year we plan to submit a self-study to ABET.

Conclusion

The newly launched B.S. in integrative engineering (name pending) at Lafayette represents a truly collaborative vision of the engineering faculty. Over a nearly 15-year process of assessment and strategic planning culminating in the past 3 years of intense focus, the addition of a formal structure to promote cross-disciplinary opportunities within the engineering division represents a transformative change for the institution. Beyond the extrinsic benefit of the new program, major intrinsic benefits were gained in the areas of community-building and creating transparent and inclusive processes, which will hopefully translate to trust and open communication regarding future resources, staffing, and course sharing. Although the launch of the program feels like a major accomplishment after a long arduous journey, of course the work is really just beginning. The program chair and advisory committee are currently developing an assessment plan and marketing materials and working with existing departments and programs to staff upcoming courses.

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