Development of a Multidisciplinary Engineering Program within the Liberal Arts Environment

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Abstract

The goal: Develop an engineering program of study to meet the needs of local industry, match the liberal arts identity of the college, and provide a pathway contained within a four-year experience for students who discover the joy of engineering after starting college. Achieving this goal is driving development of two new engineering programs: a BA degree with a major in Engineering and a BS degree in Engineering.

These programs are being developed at Carthage College, a small, liberal arts college of 2,800 students in Kenosha, Wisconsin. Discussions with local industries demonstrate significant employment opportunities in engineering; discussions with high school teachers demonstrate interest in studying engineering while remaining local; discussions with current students and alumni demonstrate that many students who come to the college are potentially interested but unsure about engineering. A pilot BA in Engineering Science built out of the physics department demonstrated sufficient interest among the student population attracted to the college, greenlighting development of the currently conceived BA and BS programs in Engineering.

The BA and BS will share the first two years of curriculum to develop a strong engineering mindset among students with project-based classes involving outside stakeholders. At the end of the second year in the program, students will choose the BA or BS pathway. For students selecting the BA, a complementary area of interest will be recommended: Environmental Science, Biomedical Applications, Business Operations, and Theatre Arts, among others. Students will take courses in this area of interest and apply an engineering mindset to develop a hybrid set of skills and experiences, followed by a semester-long senior thesis project. The BS in Engineering is designed to be ABET accreditable and will provide students with a strong technical engineering background through upper-level courses taken the junior and senior year and a yearlong capstone engineering project.

All students also complete the broad college core distribution requirements, maintaining the liberal arts standards of the college. Both programs will be completed within the 130-credit cap for the college. These programs specifically draw on the strengths of the college to create multidisciplinary engineering programs of study while maintaining the breadth of coursework and viewpoints characteristic of a liberal arts college. This paper will provide details on our development process, rationale, challenges, and goals for building these two new engineering programs.

Introduction

This work describes the development of a multi-disciplinary engineering program integrated into Carthage College, a small, liberal arts school in Kenosha, Wisconsin. The college primarily draws local students, with approximately half of students from less than 50 miles away and 30% being commuter students. While prospective students were interested in the school, data from the admissions office indicated that students were choosing other colleges due to the lack of an engineering program. The school saw this as an opportunity to recruit more students through the development of engineering. After success of an initial pilot program, we have developed a BA and BS in engineering integrated into the liberal arts core of the college. They are both multi-disciplinary engineering programs based on real projects for real stakeholders helping real people so students can practice being real engineers. With an integration into the broad liberal arts tradition, we believe students will be well-equipped to identify opportunities for engineers to better the world and communicate those opportunities to the relevant people.

Here we describe our process, rationale, and goals for building a multi-disciplinary engineering program that addresses the needs of the college, the students, local industry, and the local K-12 system.

Initial motivation

Before starting this engineering program, we worked to understand the local landscape to see if there was a need that could be filled. Carthage College is situated along a corridor between Chicago and Milwaukee in which there is a strong manufacturing presence. In the next 10 years, the overall growth rate in engineering jobs for the state of Wisconsin is projected at 13%, outpacing the 6.7% growth overall in employment opportunities[1]. Through talks with the local industry, we learned that there was difficulty recruiting trained engineers to the area. As many of our students are from the area and want to stay in the area post-graduation, they would make an attractive addition to the workforce.

Discussions with local high schools have also indicated interest for engineering. However, the nearest colleges offering engineering are either a) at a distance that commuting is unreasonable, or b) in Milwaukee, a relatively large city. Both of these cases are intimidating for students, so an option that offers an engineering degree that is local and is not in a large metropolitan area is attractive. Many existing physics students are local, so we expect a similar draw for engineering.

There is considerable anecdotal evidence from Admissions that prospective students choose other schools due to the lack of an engineering program. With recruitment from Physics faculty, some students interested in engineering do come here as physics majors and are heavily involved in co-curricular projects requiring an aspect of engineering. Those students are often well-prepared for graduate work in engineering or obtain jobs in the engineering sector upon graduation. However, we expect we lose 2-3 potential students for each student we successfully enroll because we do not have a formal engineering program that can be completed at the college. A 3+2 articulation agreement program with two universities does exist, but a very limited number of students follow that path. The cost of an additional year and the added 300+

mile distance is a barrier for many of our cost-conscious students who are interested in staying local. That program will continue to exist in parallel with the new program presented here.

As a liberal arts college, an engineering degree would need to have some flexibility to fit the overall college culture. Initially planned to fit within the college's BA footprint, a degree needed to provide some formal engineering training while still pursuing external interests such as varsity sports and musical ensembles. Many students come into college still exploring their interests, so a program with flexibility to discover engineering while in college would serve them better than programs at other institutions in the greater geographic area that provide specialized engineering degrees.

Pilot Program

The engineering program started in the physics department, with a proposal for an Engineering Science major. This major would have students take an Introduction to Engineering Design class, Statics, Materials, complete an external project, and do a one-semester capstone. This engineering curriculum would be supported by math, physics and chemistry courses, including electronics and thermodynamics through the physics department. The initial engineering science degree was not meant to be an ABET-accredited degree but a pathway for students interested in engineering to gain engineering training while integrating other interests such as business, environmental science, and data science. This degree was intended to provide strong preparation for careers in areas such as entrepreneurship, project management, architecture/design, government technology policy, patent law, and technical writing, as well as provide a foundation for further engineering study in a graduate program.

This program debuted in the fall of 2021. Courses at the college were fully in-person, but there was minimal advertisement of this program in part due to COVID the year before. Despite this, there were an initial 15 students interested. In the fall of 2022, there were approximately 35 students who indicated interest in an engineering science major entering the college, with 20 declaring an engineering major in their second semester and others still undecided. Both the fall and spring sections of the Introduction to Engineering Design course were at or near capacity (25 and 20 students, respectively). Multiple sophomore and junior students took the introductory course and have changed to the Engineering Science major, confirming our predicted need for a program students could find later in their academic career. For comparison's sake, there are traditionally approximately 20 incoming students who indicate physics as a major of interest and 10 who graduate with a physics degree each year. While some attrition is expected, the large population of interested students gave the program the go-ahead to develop further.

Further development and rationale

A director of engineering and an initial faculty major were brought in Summer 2022 to support and expand the program into a full engineering degree. While planning out the program, three key points were considered: meeting the needs of local industry, developing a strong foundation for incoming students, and integrating the liberal arts core of the college. With these needs in mind, we have developed a program with both a BA and a BS in engineering.

To better understand the needs of the surrounding community on an ongoing basis, we have built an advisory circle of external partners with ties to the geographic area. The members have backgrounds in mechanical, computer, biomedical, environmental, sales, electrical, architectural, transportation, education, packaging, process, and controls engineering as well as academia and local K-12 schools. The local industry has expressed a need for more qualified employees with an engineering background. We are not asking the industry partners what specific technical knowledge our students should have, ie not running a paper manufacturing course. We are using these partners to find out what skills they value and where they see the next generation of engineers succeeding and struggling. Consistently, the multi-disciplinary team of industry partners speak of the need to communicate clearly to a range of audiences, in both writing and presenting. The college has an extensive writing requirement and oral communication requirement, which supports our expectation of the value of the broader whole-person approach of the liberal arts environment with the technical aspects of an engineering degree.

The advisory circle also spoke to needing employees willing to take ownership of their work such that they can take appropriate risks, troubleshoot initial problems independently, and persevere even if a problem is difficult. We plan to cultivate these skills through multiple project-based learning opportunities in which students are faced with problems that do not have an obvious, straightforward solution and will require some amount of trial and error.
Input from existing faculty in physics, math, and chemistry indicated that many first-year students were starting college not prepared for an introductory calculus class. As calculus is known to be a reason students leave engineering[2],[3]. we developed an introductory quantitative reasoning course. It follows the Wright State math model[4]and is based in algebra, geometry, and trigonometry to reinforce the concepts that students should have mastered during high school. It also integrates the use of MatLab. Local industry advisors have mentioned that they look for readily transferrable skills such as MatLab in potential interns or co-op students.

Previously, MatLab and CAD work was introduced as part of a one-semester introduction to engineering design class. We have chosen to separate the MatLab and CAD components into their own courses so students could get more extensive practice in these programs. All incoming engineering students will be required to take this course, making it an opportunity for early cohort building as well.

The CAD work that had been in Intro to Engineering Design is now its own class in the second semester. The goal of separating this course out is twofold: 1. To remove the computational requirements for Intro to Engineering Design so it is accessible to any student at the college, and 2. To have students gain another transferrable skill early in their academic career.
When designing the introductory courses for this program, we also considered the local K-12 landscape, as we draw many students from these schools. Students can receive college credit for our Intro to Design class if they complete an introductory course through the Project Lead the Way high school curriculum and a capstone project at their high school. Based on expressed interest by the high schools, we are offering a section of our first-year MatLab and CAD courses in the evening in addition to the more conventional daytime class. Interested high school students can take one or both of these courses for dual credit. This credit from the PLTW courses, the MatLab course, and the CAD course would allow these students to bypass the required first year engineering courses.

To give students a hands-on experience early in their academic career, a year-long project-based course was added to the sophomore year. This project is to be based on needs from an external stakeholder (industry, non-profit, community organization, etc). With this project, students will have to take on a variety of roles as they design, prototype, build, and test a solution for the problem at hand. The students will have to address engineering challenges across any relevant disciplines to complete the project. As this project will be required for all engineering students, it can help guide students to the path they want to take as well as providing them with a concrete example of work to put on a resume.

By the end of the sophomore year, students will choose their future path: the BA or the BS. The same engineering classes will be open to the BA and BS students, but the number of credits of technical upper-level courses and the ability to integrate other areas of interests differs.

The BA degree is meant to provide students with a strong engineering mindset while integrating their other interests into their degree. A unique component of the Engineering BA compared to many engineering programs comes within the developed "emphasis areas," such as technical theater arts, environmental science, physics, and business operations. More emphasis areas will be added as the program develops. Students will take a set of four courses in the area of their choosing. In development of these areas, courses were selected both for relevance and availability—the classes are not typically full, leaving room for engineering students. These areas also make it easier for a student to double major or minor in an area other than engineering. These four "emphasis" courses would replace technical courses in a traditional engineering BS. We believe these pre-defined emphasis areas show that we have thoughtfully and strategically constructed the BA program. It is not an afterthought for students who realize they do not want to pursue a professional engineering degree but another path preparing students for engineering-adjacent work or other work not requiring licensure. Anecdotal evidence from conversations with current students show interest in these pathways and combining engineering with another area of interest.

The BA ends with a one-semester cumulative thesis project, as is common across the college. Students would be expected to integrate their engineering knowledge and emphasis area of choice to produce an assessable document, whether that is a built structure or costume, formal paper, website, business plan, or other sort of work.

The BA pathway can also be completed in 3 years. While, again, it will not qualify students to sit the FE, discussions with graduate programs have determined that it can be sufficient preparation for graduate school in multiple engineering disciplines, especially if students work closely with their advisor to judiciously select courses. This allows a student who discovers engineering later in their college career to still have a path toward an engineering future while still finishing their undergraduate degree within four years.

In the engineering BS, students will take more technical classes their junior and senior year, culminating in a year-long capstone project (see chart). The BS degree can be completed in four years without taking an overload or summer courses, if students come in ready for college-level math, defined by ABET as calculus or above. While our quantitative reasoning MatLab course

will reinforce concepts students should have learned in high school, students without the necessary preparation for calculus will be required to take a college algebra course. We will work with these students to carefully choose elective and general distribution requirements to try to fulfill all of those requirements in the 4 years. We are also negotiating an additional one-course January term for these students beyond the two included within the normal college tuition to ensure that this degree could be completed within the 4 years. Initial classes have been chosen to include the important factors for multiple engineering disciplines and prepare students to pass the "other disciplines" engineering FE exam. Senior-level courses and an optional co-op experience will allow students to delve further into a specific area of engineering. As the program develops, we plan to add additional junior-level technical courses as appropriate for our majors. These courses would move beyond the content required to pass the FE exam and focus on disciplines and topics of interest to our students, allowing further specialization.

The BS degree granted will be in engineering, with no specified discipline. With the size of the program and the number of faculty, splitting the program into sub-disciplines is not a reasonable possibility if we would want to have the depth necessary for multiple concentrations. Instead, we have made the degree intentionally multi-disciplinary. The degree will expose students to the main components of engineering and the engineering mindset. They will take courses covering the design process, statics, solid mechanics, materials properties, electronics, thermodynamics, heat transfer, fluids, and manufacturing processes. The sophomore yearlong project and the senior capstone will both contain projects from a variety of disciplines, with students expected to be able to take on a project regardless of initial discipline. Our advisory circle is multi-disciplinary, ranging from electrical and mechanical to packaging and transportation. These industry partners support this approach and believe students can learn the concentration-based technical skills necessary when they get their first job.

While offering both a BA and a BS in engineering is rare, there are some comparable programs. Dartmouth College offers both paths, with the BA a required step on the path to the BS. Over 80% of students pursue the BS degree. Approximately 40% of students complete the BA and BS degree within 4 years, while others require an extra semester or two[5],[6]. Trinity College in Connecticut also has a BA and BS program. Similar to our new program, students pursuing the BA chose a "cognate" area in a different department to combine various interests. However, about 90% of students who graduate from Trinity with an Engineering degree do so with a BS degree[7]. While we cannot accurately predict our student population, we expect to have a larger population of students intentionally choosing the BA degree and seeing it as an alternative with value in its own right. It is both an on-ramp for students finding engineering late and an off-ramp with added value for students who realize they want to be engineering-adjacent, not engineers.

BA degree with major in Engineering		**BS in Engineering**	
Math and Science Requirements			
EGR 1020 Comp. Reasoning with MATLAB	2	EGR 1020 Comp. Reasoning with MATLAB	2
MTH 1120 Calculus I	4	MTH 1120 Calculus I	4
MTH 1220 Calculus II	4	MTH 1220 Calculus II	4
MTH 2120 Multivariate Calculus	4	MTH 2120 Multivariate Calculus	4

MTH 2020 Differential Equations *or* MTH 3050 Statistics	4	MTH 2020 Differential Equations	4
		MTH 3050 Statistics	4
PHY 2200 General Physics I	4	PHY 2200 General Physics I	4
PHY 2210 General Physics II	4	PHY 2210 General Physics II	4
CHM 1010 General Chemistry I *or* BIO 1110 Biology I	4	CHM 1010 General Chemistry I	4
Engineering Requirements			
EGR 1100 Introduction to Engineering Design	4	EGR 1100 Introduction to Engineering Design	4
EGR 1200 Visualization & Modeling *or* EGR 1300 Managing Engineering Ventures	2	EGR 1200 Visualization & Modeling	2
		EGR 1300 Managing Engineering Ventures	2
EGR 2700 Engineering Practice I	4	EGR 2700 Engineering Practice I	4
EGR 2710 Engineering Practice II	4	EGR 2710 Engineering Practice II	4
EGR 2100 Statics & Solid Mechanics	4	EGR 2100 Statics & Solid Mechanics	4
Engineering Electives (EGR 3000-level or above)	8	EGR 3100 Engr Materials	4
● EGR 3100 Engr Materials		EGR 3600 Dynamics	4
● EGR 3600 Dynamics		EGR 3120 Electronics	4
● EGR 3120 Electronics		EGR 3400 Thermo-Fluids	4
● EGR 3400 Thermo-Fluids		EGR 4300 Engr Mgt & Economics	2
● EGR 4300 Engr Mgt & Economics		EGR 4500 Analysis & Meas of Engr Systems	4
● EGR 4500 Analysis & Meas of Engr Systems		**Engineering Electives** (EGR 4000-level or above)	8
● EGR 4100 Nanomaterials		● EGR 4100 Nanomaterials	
● EGR 4110 Internet of Things		● EGR 4110 Internet of Things	
● EGR 4120 Mfg Processes & Design		● EGR 4120 Mfg Processes & Design	
● EGR 4130 Mech of Human Motion		● EGR 4130 Mech of Human Motion	
● EGR 4550 Engr Coop Experience		● EGR 4550 Engr Coop Experience	
Senior Capstone Experience			
EGR 4900 Senior Capstone Project	4	EGR 4910 Engineering Capstone I	2
EGR 4990 Senior Capstone Completion	0	EGR 4920 Engineering Capstone II	2
Total Credits	60	**Total Credits**	88

Table 1. Major requirements for the BA (left) and BS (right) degrees.

Challenges

As Carthage College prides itself on its liberal arts core, the engineering program needed to fit into that liberal arts model. That meant cultivating the core aspects of the liberal arts model, especially a whole-person approach to collegiate development, a reflective framework for students to grow as learners and people, and the ability and desire to be a lifelong learner.

Engineering is traditionally a professional degree, thus there was initial wariness about the ability for the new program to integrate into the greater college. The pilot engineering science degree primarily drew on existing classes and was a subset of the physics department. The revised BA and new BS require more new classes and provide a professional degree. This evolution caused concern among other faculty members who had concerns that the degrees would not fulfill the liberal arts spirit of the college.

This program also was developed with the plan of a cohort of five faculty and a building renovation. This is a non-negligible financial commitment during a time where universities are facing declining enrollment and still feeling the effects of COVID-19. While these financial decisions were determined at an administrative level above the faculty, we did not want ill-will for a newly developed program. As the professional nature of the program was also a concern, we made sure to work with a variety of departments as we developed the emphasis areas for the BA. These ties are mutually beneficial for both engineering and the emphasis department while integrating the engineering program more thoroughly into the college as a whole.

In addition to the cultural fit of engineering, we faced the practical challenges of fitting the full 30 credits of math and science and 45 credits of engineering topics required for EAC-ABET accreditation into a 4-year degree. Students must take a total of approximately 40 credits of college core courses, and a degree must fit in the 130-credit cap of the college. To provide room for coverage of the breadth of topics on the FE exam, some courses have been combined when there is a reasonable relationship, namely statics and mechanics are one class, and thermodynamics, fluids, and heat transfer is a single class. In addition, the 12-credit writing requirement and oral communication requirement can be met in full through engineering courses.

However, the schedule allows minimal room for deviation and requires an almost immediate start, unless students transfer in college credit. We recognize that some students are unsure as to their pathway and may not discover an interest in engineering immediately. The liberal arts nature of the school encourages exploration for those who are uncertain, so a pathway that could be started at a later point in the college timeline was necessary. This problem led us to ensure the BA in engineering could be completed as long as a student took the introductory design course and reached Calc I by their second semester sophomore year.

Future plans

The first class of students for this BA/BS program will be entering the fall of 2023, with the current Engineering Science degree being sunsetted once the current cohort graduates. All incoming students will start in the same classes. We will track the number of students pursuing each path and see if there is a correlation between engineering grades and the path taken. As we intend the BA and BS to be distinct, complementary programs, we want to ensure that the BA does not become a consolation degree for students who are struggling in engineering. We will also track our attrition rate and where/when students transfer in or out of the program. Our first major checkpoints will be the attrition after year 1 (spring to fall 2024) and the BA/BS split after year 2 (advising for fall 2025 classes).

In all, this program was designed to offer students a strong foundation in the engineering mindset and the choice of integrating that mindset with another field in the BA or deepening their technical skills with the BS. The initial thrust for the program came from recognition of mutually beneficial opportunities within the college and community. Conversations with local industry partners and K-12 schools further guided our development so that students would be engaged and also learn the "soft skills" necessary to thrive in industry. In the development, we prioritized real life projects and transferrable skills while trying to preemptively address the sticking point of calculus thought our introductory quantitative reasoning with MatLab course. Our course offerings are meant to allow students pursuing the BS degree to pass the FE exam for "other disciplines" and give students a multi-disciplinary understanding of engineering. Though all of this, we needed to balance the credit hours with those needed to complete the somewhat extensive general curriculum typical of a small, liberal arts school. While student data mapping the success of this program will still need to be taken, we hope this program provides students with preparation to go both into engineering and engineering-adjacent jobs that are plentiful in the local area.

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