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Exploring Student Impressions of and Navigations through a Flexible and Customizable Multidisciplinary Engineering Program

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Exploring Student Impressions of and Navigations through a Flexible and Customizable Multidisciplinary Engineering Program

Abstract

Last year, the College of Engineering and Applied Science at the University of Colorado Boulder inaugurated a flexible, customizable and design-focused multidisciplinary undergraduate engineering degree program, built on a common engineering core, with a hands-on engineering design focus throughout all four years. Predicated upon the belief that students know what is best to meet their own career and personal interest needs, the curriculum branches out so students choose many courses to pursue their individual passions. Different than the traditional restrictive engineering curricular models that act as barriers to student migration into engineering programs, the curricular flexibility and choice in the *Engineering Plus* (e+) program makes transferring into the program more navigable, without necessarily extending time to graduation and its corresponding cost. The academic pathways of individual students who have migrated into and out of the budding e+ program are explored to understand who a multidisciplinary, choice-enriched, design-focused program is drawing in and who is opting out. Early program findings, including results from two student focus groups, serve as an opportunity to learn from engineering students experiencing academic flexibility and customization, decipher the lessons they hold for engineering education policymakers and educators, and pose the creation of more curricular choice as another pathway to broaden participation and improve engineering educational outcomes.

Introduction

In 2008, a multi-institutional, multi-year study revealed that engineering differs from other majors by "a dearth of female students and a low rate of migration into the major."[1] And, the rigid, often lock-step nature of engineering programs presents a barrier to student migration into engineering programs. Others have cited the need for increased flexibility in engineering degree programs and have experimented with novel approaches for flexible baccalaureate programs.[2,3,4,5] In a study that compared the students in Purdue's highly flexible and course choice-friendly multidisciplinary engineering (MDE) program, it was found that "male students in MDE are more likely to be intuitive, feeling and perceptive than male students in other engineering majors," leading to the conclusion that the "development of flexible curricula that are attractive to (and retain) students that are less likely to stay in other engineering programs may be low-hanging fruit in reforming engineering education."[5]

Previous studies demonstrated that undergraduate engineering students across the nation are allotted minimal opportunities to explore academically through choosing their courses, especially compared to their non-engineering peers on campus.[6,7] In a study that spanned more than 300 ABET-accredited engineering programs from top-ranked engineering schools, it was found that engineering students were afforded a median of just one free elective course (2% of total degree), compared to non-engineering programs on the same campuses that afforded students a median of almost one-quarter of the total degree (24%) as free elective opportunities.[7] This minimal free elective convention is unnecessary from an accreditation standpoint (and perhaps a content standpoint), as demonstrated by highly ranked, exceptional schools who instead opt to afford

engineering students with free elective opportunities for 8-19% of their total degree coursework.[6] It is hypothesized that introducing more curricular choice and flexibility into engineering degree programs is a better match for students' psychological and developmental needs,[6,7] and that providing more choice stands to benefit the quality of an engineering education.

In a study spanning more than 100 top-ranked chemical, civil, electrical and mechanical engineering programs, a median of 78% of the engineering degree program curricula consisted of required "technical" coursework (in engineering, math or natural science), versus a median of 20% required "non-technical" coursework (outside of engineering, math or natural science).[7] This median allocation combined with the commonplace zero to one free elective course opportunity meant that engineering students in the studied programs were afforded few opportunities to pursue a balanced, liberal education through additional coursework in the humanities and social sciences. From an accreditation standpoint, this convention of devoting more than three-quarters of an undergraduate engineering program to required technical content is unnecessary; ABET requires only two and a half years of technical coursework (63%) of a four-year degree.

The Engineering Plus *(e+) Program at the University of Colorado Boulder*

The College of Engineering and Applied Science (CEAS) at the University of Colorado Boulder offers nine ABET EAC-accredited engineering programs, each of which exhibits the minimal free elective and high technical requirement curricular model found to be so common across engineering programs nationwide. However, in 2013, a highly flexible and customizable engineering program, *Engineering Plus* (e+), was added to the college. The e+ program requires students to complete a common design-infused engineering *core*; choose an engineering discipline *emphasis* (consisting of five courses within aerospace, architectural, civil, electrical, environmental or mechanical engineering); as well as choose a *concentration*—a sequence of four or more courses of increasing content sophistication either within or external to engineering—such as business, environmental policy, Spanish and Latin American cultures, or CU Teach Engineering, a unique pathway that couples the engineering degree with preparation for secondary math or science teacher licensure.

Students also have substantial freedom to further explore academically through free electives; as the e+ program provides students with up to 14% of total degree credit hours as free electives. And, up to 37% of the total degree can be devoted to non-technical pursuits, depending on student interests.

Program Evolution from STEM Teacher-Licensure Preparation Focus to a Flexible, Customizable, Design-Focused Engineering Program

To fully share the story of e+, it is important to clarify that—though it may have been prescient to do so—the program did *not* originate from a desire to create a flexible, customizable, design-focused and multidisciplinary program; and yet, that is an apt description of the program that was ultimately created. Rather, e+ was born from the desire to streamline and optimize an engineering degree (designed for accreditation) to support a secondary science and math teacher licensure preparation pathway in an effort to address the shortage of K-12 STEM teachers and the deficient teaching of STEM subjects in U.S. K-12 schools.[8] By creating a nationally replicable model to prepare teachers with rich content knowledge in both engineering and math

or science, the intent was to make the engineering education enterprise a meaningful contributor to the development of excellent, content-rich secondary STEM teachers. And, preliminary data suggested that our engineering students were interested in teaching; in 2012, almost 1,000 CU Boulder undergraduate engineering students (approximately one-quarter of the engineering college's undergraduates) participated in a survey wherein 25% of respondents "agreed" or "strongly agreed" that they "would be interested in earning a grades 7-12 science or math teaching license while [they] earn [their] engineering degrees," including 23% of male, 31% of female, and 42% of Hispanic respondents. For comparison, only 13% of students indicated the same level of interest in fulfilling medical school admission requirements, and only 8% of students had the same level of interest in attending law school after completion of an undergraduate engineering degree.

Engineering design is a powerful vehicle for math and science learning in K-12 classrooms, standing to improve student learning and achievement in those subjects, and increase student technological literacy, awareness of and interest in pursuing engineering as a career.[8] With engineering, science and math teacher development in mind, engineering design was therefore carefully woven in and through the fabric of the degree program.

Regardless of national need and student interest, realizing this program vision would require the integration of design-focused engineering curriculum, extensive science or math content, education courses, and student teaching—something we were not sure was possible within eight semesters of coursework and one semester of student teaching. Thus, the preliminary program design required a yearlong feasibility study with extensive benchmarking, and secondly (after reaching the data-driven conclusion that this vision was achievable and worthwhile) a careful, course-by-course scaffolding of the program to ensure that graduates would emerge with both a quality engineering *and* secondary science or math teacher education. Graduates would need expansive preparation to both earn secondary science or math teacher licensure and work in the engineering industry—providing a flexible and multi-faceted professional pathway.

College feedback on the preliminary program design indicated that it was worthy of implementation, but that the work was not done: now that a quality, streamlined and design-based engineering degree was created, why wouldn't we expand the degree program vision to facilitate student pursuit of other multidisciplinary interests—not just teacher preparation—in concert with engineering? This college-wide feedback also echoed student voices; from the same college-wide survey in which students expressed interest in teaching, almost half of the ~1,000 undergraduate engineering respondents indicated that they would like the flexibility to customize their engineering degree programs through individualized, negotiated curriculum. And so, the program was further developed into the *Engineering Plus* program that it is today, enabling students—through their *concentrations* and free electives—to pursue CU Teach Engineering or another specialty of their choosing. The engineering design-focus that was originally integrated with K-12 teacher preparation in mind is also now viewed from the expanded perception of preparing multidisciplinary engineering graduates skilled in *design-thinking*, able to broaden the participation of engineers in society with multifarious applications of this valuable thinking approach.

In 2013, the new *Engineering Plus* program began accepting transfer students and the first cohort of first-year students began in fall 2014. This paper explores the academic pathways of individual students who migrated into and out of e+ to understand who this multidisciplinary, choice-enriched program is drawing in and who is opting out, as well as the impact of the e+ program on the engineering college. Specifically, we explore the following research questions:

- How do the required courses and course choice opportunities in the *Engineering Plus* program compare to those of the traditional, discipline-specific engineering programs in the College of Engineering and Applied Science at CU Boulder?
- How do students perceive the e+ program curriculum?
- Who is the e+ program drawing in and who is opting out?
- How is the presence of the e+ program impacting student pathways through, and educational outcomes from, the engineering college at CU Boulder?

Probing Student Impressions of and Navigations through the *Engineering Plus* Program

In fall 2014, two focus groups were conducted with a total of 10 e+ students to explore their perceptions of the program and curriculum. These focus groups were also explored in a previous paper on creating community in a flexible yet technical engineering program.[9] The six main focus group questions are included in Appendix A; in some cases, clarifying and/or follow-up questions were also asked. Two of the 10 focus group participants were female. The participants included four first-year, four sophomore, and two junior students, with a range of *emphases* including aerospace, civil, environmental and mechanical engineering, and a range of *concentrations* that included business, entrepreneurship, finance, CU Teach Engineering and a leadership program. All but one of the six non-first-year student participants transferred into *Engineering Plus* from another engineering major in the college; and one student transferred into e+ from a biology major. Student quotations and impressions from these focus group sessions are presented throughout this paper.

The information included in this paper also draws from an extensive, informal interview with the program advisor, the personal experiences of the authors who were intimately involved in the program since its design and launch, and university-captured enrollment and retention data on CEAS students. The curricular flexibility and choice that is central to the e+ program has necessitated consistent and comprehensive advising of the students as they matriculate through the program; as such, the program advisor's impressions were of great value.

The Flexible, Customizable, Design-Based *Engineering Plus* Program

The *Engineering Plus* program is a design-based customizable undergraduate engineering degree program that requires a total of 128 credit hours for graduation (the same as the nine existing accredited engineering programs in the college). The curriculum is comprised of four or more design courses, five design-infused core engineering courses, at least 15 credits within a *disciplinary emphasis* and 12 or more credits in a pre-approved *concentration* either within or external to engineering (Figure 1).

Figure 1: The *Engineering Plus* (e+) program design.

Concentrations must be a meaningful sequence of courses, either technical or non-technical in nature, and traditionally culminate in a 4000-level course. To date, 17 concentrations have been approved for the major, including CU Teach Engineering (the first concentration), environmental policy, entrepreneurship, Spanish and Latin American cultures, pre medical, and technology arts & media, with the option for students to propose new concentrations, subject to program approval (see Appendix B for a complete list of approved concentrations).

The first students graduated from e+ in fall 2015. The program will seek ABET-accreditation in 2017, concurrent with the next date of comprehensive review for existing ABET-accredited programs in the college.

Table 1 details the e+ curriculum using the example of a mechanical engineering emphasis and is presented in comparison to the curriculum for the EAC-accredited traditional mechanical engineering degree program in the CEAS.

Table 1: Comparing the *Engineering Plus* mechanical emphasis curriculum to the CEAS's traditional mechanical engineering program curriculum.

Engineering Plus **Mechanical Emphasis**		**Traditional Mechanical Program**	
Course	**Credits**	**Course**	**Credits**
Computer Science	4	Computer Science	4
Introduction to Mech. Eng.[1]	1	Professional Seminar	1
Materials Science	3	Materials Science	3
Statics[1]	3	Statics	3
Circuits/Electronics	3	Circuits/Electronics	3
Data Analysis, Exp. Methods	4	Data Analysis	2
Thermodynamics[1]	3	Thermodynamics	3
Mechanics of Solids	3	Mechanics of Solids	3
Fluid Mechanics[1]	3	Fluid Mechanics	3
Dynamics	3	Dynamics	3
Component Design	3	Component Design	3
System Dynamics	3	System Dynamics	3
		Computational Methods	3
		Heat Transfer	3
		Computer-Aided Design	4
		Thermodynamics 2	3
		Manufacturing	3
		Measurements	4
		Mech. Eng. Technical Elective[2]	6
		Technical Electives[3]	6
Design: First-Year Engineering Projects[*]	3	First-Year Engineering Projects[*]	3
Design: Engineering for the Community[*]	3		
Design: Invention and Innovation[*]	3		
Capstone Design[*]	6	Capstone Design[*]	6
Engineering Total	**51**	**Engineering Total**	**75**
Physics 1, 2, and Lab	9	Physics 1, 2, 3 and Lab	12
Chemistry[1]	4	Chemistry	4
Basic Science Total	**13**	**Basic Science Total**	**16**
Calculus 1, 2, 3	12	Calculus 1, 2, 3	12
Differential Equations	4	Differential Equations	4
Math Total	**16**	**Math Total**	**16**
Writing[1]	3	Writing[1]	3
Human., Social Sci. Electives[3]	15	Human., Social Sci. Electives[3]	15
Humanities, Social Sci. Total	**18**	**Humanities, Social Sci. Total**	**18**
Concentration[1]	**12**		
Free Electives[4]	**18**	**Free Electives[4]**	**3**
Total	**128**	**Total**	**128**

[*] *Engineering design course.* [1,2,3,4] *correspond to course choice-types in Table 2.*

To highlight the comparative *course choice opportunities* (such as free electives, technical electives, humanities electives, etc.) made available in *Engineering Plus* versus the college's traditional mechanical engineering program, we categorized all program course choice opportunity credit hours into one of four choice types: 1) courses chosen from a list of options, 2) courses chosen within one department, 3) courses chosen from more than one department or 4) free electives. Table 2 presents a comparison of degree program credit hours that provide course choice opportunities, by choice-type.

Table 2: Comparing course choice opportunities in the *Engineering Plus*, mechanical emphasis curriculum to the traditional mechanical engineering program curriculum.

Course Choice Category	Definition	Credit Hours (out of 128)	
		DEF, Mech. Emphasis	Traditional Mechanical
1	Courses chosen from a list of options, such as "choose one of the following four courses."	29	3
2	Courses chosen from one department *or* engineering electives, such as "history elective," "mech. engineering elective."	0	6
3	Course choices outside of engineering, chosen from more than one department (but not a free elective), such as "technical elective," "humanities elective."	15	21
4	Free electives; course choice opportunities with no restrictions.	18	3
Total Credit Hours with Course Choice		**62**	**33**

Depending on the *concentration* chosen, the e+ program affords students up to 18 credit hours of free electives (14% of total 128 credit hour degree), compared to the median of free elective credit hours afforded to students across the other nine engineering programs in the CEAS of four credit hours (3% of total 128 credit hour degree), which is much closer to the previously reported national minimal free elective norm for engineering students.[7]

The e+ program requires that students take 18 credit hours of coursework in the humanities and social sciences (14% of total degree), which mirrors the requirement outlined in seven of the nine accredited engineering programs in the CEAS (two programs require 21 credit hours). In terms of technical versus non-technical balance, the e+ program differs in the extent to which students are able to select non-technical coursework in the arts, history, philosophy, etc., to realize a rich, liberal engineering education should they so choose. *Engineering Plus* students can devote up to 48 credit hours (just over 37% of total degree) to non-technical pursuits, while most engineering students in the college are limited to taking one or two non-technical courses in addition to the basic requirements.

The *Engineering Plus* Student Body

To date, a total of 92 students have enrolled in the e+ program at some point, including 27 female (29%) and 65 male (71%) students.

Table 3: *Engineering Plus* student counts from fall 2013 – 2015.

	First-Year	Sophomore	Junior	Senior	Total
Fall 2013	n/a	0	1	0	1
Spring 2014	n/a	1	0	2	3
Fall 2014	24	10	4	4	42
Spring 2015	17	12	8	7	44
Fall 2015	25	12	14	14	65

Of these 92 students, 56 (60%) matriculated directly into e+; 36 students (39%) migrated into the program from another major. To put this substantial in-migration percentage into context, 36 of the 65 students (55%) enrolled in the e+ major in fall 2015 migrated *into* the program from elsewhere in the engineering college, compared to the college's traditional mechanical program's in-migration of just 7% of its enrollment (71 of 978 students) during the same time period.

We found that the direct-matriculation students have different relationships *to* and pathways *through* the e+ program than the in-migration students, which is discussed in more detail below.

The e+ student body characteristics are similar to those of the CEAS (Table 4).

Table 4: Comparing the e+ student body to the College of Engineering and Applied Science.

Demographic	*Engineering Plus*	CEAS*
% In-state residents	74%	62%
% Female	29%	25%
% Underrepresented minority	16%	11%
Average high school GPA	3.88	3.79
Average ACT-Comp	28.7	29.1
Average ACT-Math	29.8	29.7
Average ACT-English	28.4	28.6
Low-socioeconomic status (SES)	18.5%	20.9%

Note: "Low-SES" proxy is defined as expected financial contribution (EFC), 150% of Pell Grant eligibility and under (Level One).

**Includes students that entered the college in fall 2012 and beyond.*

Student Pathways Into and Out of *Engineering Plus*

Direct Matriculation into e+

To date, two cohorts of new students have matriculated into e+: fall 2014 and fall 2015. The fall 2014 cohort consisted of 29 students; of those, 26 (90%) continued in the e+ program after the first semester while just six (21%) remained enrolled in the program after three semesters. This low retention result is discussed shortly. One student who matriculated in spring 2015 is continuing with the program. The fall 2015 cohort included 26 students, 22 (85%) of whom continued with the program into the second semester.

Of the 56 students who matriculated directly into the e+ program thus far, 31 are still in the program after one to three semesters, leaving 25 who have either left the program (22) or are not currently enrolled in the program due to academic suspension or for unknown reasons (3). Of the 22 students who matriculated into e+ and later transferred out, 16 (73%) left the program to pursue one of five different engineering majors, while three (14%) pursued computer science/ technology degrees in the engineering college. The remaining three left engineering to pursue economics, finance and integrative physiology majors.

Students who left e+ were generally in good academic standing at the time of departure with an average GPA of 3.03 (ranged from 1.89 to 3.92).

The advisor ascribed the notable migration of e+'s direct-matriculation students *out* of the program and into discipline-specific engineering programs to three distinct shared student motivations: 1) students who developed a new or greater passion for a more traditional, discipline-based engineering program; 2) students who strategized acceptance to the CEAS through the (not enrollment-limited) e+ program with the intention of transferring later to a major they perceived as enrollment-limited; and 3) students who inadvertently arrived to the e+ program thinking that it was the engineering college's "open-option" major.

Perhaps not surprisingly, the program advisor noted that many first-year students did not arrive with a curricular plan for themselves and were slow to select their concentrations and engineering emphases. Many seemingly did not pick the new e+ program for the curricular choice and flexibility it affords (unlike the transfer students who were drawn in by this feature). The third group of first-year direct matriculation students—who arrived to the program more by happenstance and less by conscious, informed choice about the program—were misleadingly influenced to do so by the, in retrospect, unfortunate initial naming of the program. We deviate slightly to explain this program naming misadventure since its effects have rippled through the student impressions of, and navigations through, e+.

The Program Name Misadventure

The *Engineering Plus* program was initially named the *General Engineering Plus* program, influenced by our intention to accredit the degree program under ABET's "general" criteria. Across the two focus groups, sophomore and junior students described the process of needing to *explain away* the "general" when describing the degree program to peers, parents and prospective employers, because people incorrectly (but understandably) concluded that "general" implied a broad and/or sampling engineering degree. Also evident from focus group findings was the notion that some first-year students, unsure of their interests in engineering, inadvertently

chose e+ due to their interpretations of "general," mistaking it for their more appropriate placement in the college's open-option program. The e+ program advisor cited frequent similar experiences with students who were seeking the open-option initial "major" and found their way to her office to inquire about the e+ degree program, thinking that it was open-option.

Following the 2014-15 academic year, the program team unanimously requested that the university approve a degree program name change to *Engineering Plus*, citing student, parent, industry and college-wide sources of confusion and misconceptions resulting from the use of the word "general" in the degree program name. The university approved the name change request in fall 2015; but it is still listed on the fall 2016 common application as the *General Engineering Plus* program, likely impacting the program's efforts to attract and retain first-year students until fall 2017.

In short, a program's name matters. As outlined above, e+ is a specialized *design-focused* degree program, requiring students to focus in engineering design thinking and doing, and an engineering disciplinary *emphasis*—while developing a secondary area of expertise via the *concentration*. This multifaceted specialization is distinctive amongst the traditional discipline-specific engineering programs in our college. The authors hope that removal of "general" from the program name better reflects the unique combination of specificity and customizability afforded by the program curriculum and that the renaming will help the program grow in size and stature. We also hope that this lesson-learned serves as a cautionary tale to other colleges interested in creating a new program accredited under the "general" criteria.

Engineering Plus *In-Migration Pathways*

Of the 36 students (15 females, 21 males) who have migrated *into* the e+ program since its fall 2013 soft launch, the majority (n=33) came from 11 majors across the engineering college and three migrated from a major outside of the college. Many students (7 of the 36) had explored more than one major before migrating into the e+ program. Information provided by their former program advisors and the college website commonly sparked migration into e+. Students migrated in at every academic level; only four transferred into e+ in their first years on campus, 17 in their second years, six in their third years, and a surprising nine in their fourth years or later.

It is noteworthy that, thus far, only three students have transferred into e+ from outside of the engineering college. Prerequisite "gatekeeper" courses most efficiently taken early in the college experience (such as three semesters of calculus and differential equations) could be keeping potentially interested non-engineering students away. It is hoped that, over time, the curricular flexibility and free electives inherent in the e+ curriculum make the program the engineering college's most navigable in-migration destination—and thus an increasingly important strategy to broaden participation in engineering by young adults interested in divergent, non-traditional futures in non-governmental organizations (NGOs), politics, finances, etc., built upon the solid technological foundation of an engineering education. Thus, it is possible that the e+ curricular model could offer an antidote to the nation's notoriously low rate of in-migration into engineering education.[1]

Differential retention of in-migration students. Thirty-two of the 36 e+ in-migration students (89%) have been retained in the program thus far (two graduated in fall 2015, the program's first

graduates), while only three in-migrators (all from the college's open-option initial program) later transferred out of e+ (one left the university, one migrated to computer science, and the third migrated to architectural engineering).

More than just engineering. The 32 in-migrators found their way to e+ for myriad reasons. A theme across one group of students was the desire to do "more than just engineering," to do "engineering *and*." In the words of one male student,

> "…my [interest] goes back to kind of a design-based piece, because that was my favorite part, and then I had an interest in finance. I noticed that was one of the other emphases you could take so that's what I chose to do."

Another male student who transferred into e+ and is pursuing a prestigious university leadership program for his concentration stated:

> "I switched into [e+] because I am taking a lot of coursework outside of the school of engineering and I was frustrated it didn't apply towards my degree and that I was feeling very, like I had to be doing all these different things at once. And [e+], the idea that it catered towards people who had interest outside of engineering as well really excited me."

The "engineering and" students were generally thriving academically in engineering majors prior to their transfers into e+; they tended to transfer into e+ knowing exactly how they wanted to employ their concentrations and free elective opportunities. Many of the "engineering and" students chose the CU Teach Engineering concentration; one found that he could "do all the engineering and the teaching," and a woman in the CU Teach Engineering concentration described:

> "I think there is a difference in interest [in] engineering [between e+ students and other engineering students in the college], but something else in addition to that. Whereas, all the other people that I have in my classes, they're just strictly civil engineering or architectural engineering. They are wanting to be doing strictly that and go into a firm and do that, where not all of us do."

Several CU Teach Engineering student pathways are detailed in the CU Teach Engineering section below.

The perception of choice and flexibility as easier. In other cases, students who transferred into the *Engineering Plus* program were not thriving academically and perceived the e+ program's flexibility and choice as an "easier way out" due to the fewer total engineering requirements (see Table 1). The advisor cited numerous instances of academically struggling students from other engineering majors seeking her out to inquire about e+. These students were often surprised (and disappointed) to hear that the program required all the same math courses and grade requirements as the traditional engineering programs in the college. Sometimes students did not do well in a course or courses that e+ does not require, and the e+ program presented an opportunity to complete an engineering degree, sometimes without extending time to graduation due to repeating those required courses.

This group of "hopefully it's easier" students has been the subject of an ongoing philosophical dialogue amongst the *Engineering Plus* faculty regarding finding the balance of how to serve students who are struggling in other engineering programs and support enhanced engineering in-

migration (thus boosting engineering college retention), while simultaneously not becoming a "dumping ground" for students who are not performing at a high enough level in the "real" engineering disciplines. However, time and again we have learned that to engage a prejudiced perception of struggling students as "lost causes" results in a loss to the college. While engineering designers claim to "fail often to succeed sooner," a student's initial low success in the engineering curriculum is too often prejudicially viewed as terminal. The first student who came to *Engineering Plus* was originally enrolled in the college's traditional chemical engineering program and academically drowning in organic chemistry (a required course for chemical engineering majors, but not e+ majors). She had decided to leave engineering altogether to pursue a business major. An advisor informed her about e+, and she ultimately switched to pursue the major with an environmental engineering emphasis and a business minor concentration. She graduated with her bachelor's degree in fall 2015 after 11 semesters at the university (6 spent in chemical engineering and 5 in e+), and was singled out by the Dean during commencement for excellence. Her new career position in technical sales blends her unique preparation at the crossroads of engineering and business; she credits the e+ program for keeping her in engineering. This program alum remains unwavering in affirming that if it were not for the *Engineering Plus* program, she would have left engineering and the engineering college altogether.

A passion for engineering design. Other students were drawn to e+ because of a positive experience in the first-year engineering projects class that ignited their passions for engineering design, the curricular focal point of the e+ program. Design is integrated into each of the e+ engineering core classes in addition to the five semesters of explicitly focused hands-on engineering design courses. In the words of one student who migrated into e+:

> "I wanted to finish an engineering degree in four years and so doing extra stuff, like entrepreneurship or business, I didn't want a chance of that extending my time. And also, I think that the design aspect of the degree is also attractive to me, not necessarily in that I'll be in a field where I'll be doing prototyping, but in the design process, you learn a lot of critical, analytical thinking that is applicable in all fields of engineering. So kind of… digging down deeper into that is what attracted me."

Another e+ student stated:

> "…when I heard there were a bunch of project classes that were very hands-on, that also really excited me because I hadn't really had any classes except for the freshman project class where I made something that I could look at and feel satisfied about. So I really liked that."

CU Teach Engineering: "The Best Should Teach"

Included in the *Engineering Plus* student body are 11 engineering students pursuing the unique STEM teacher licensure preparation concentration, CU Teach Engineering, which prepares them for secondary math or science teacher licensure concurrent with the engineering degree in just nine semesters.

This pathway was founded on the notion that "the best should teach," and many of the students who have chosen this concentration are exceptional. They are highly committed, with a passion for teaching and strong motivation to pursue the Teach Engineering concentration. One male

student was originally pursuing a double degree in mechanical and electrical engineering, but found out about the e+ teacher licensure pathway and in-migrated in spring 2014. He is now pursuing an electrical engineering emphasis, a CU Teach Math concentration, and an applied math minor. He also works at a nationally recognized research institute. One female student came to e+ from civil engineering in fall 2013 when she found out about the teacher licensure preparation program. During a focus group she explained, "I was always trying to decide between education and engineering, so when I saw there was the combined education/engineering opportunity, that's exactly what I wanted to do, so I decided [e+] was the perfect place." She is pursuing a civil engineering emphasis, a CU Teach Math concentration, and a double-major in applied math. She plans to graduate from e+ in fall 2016 following nine semesters in the engineering college, one of which is student teaching.

Engineering Plus program faculty presented and served on a panel at this year's annual UTeach conference where attendee feedback confirmed that this licensure pathway for engineers is pioneering and—we hope—may ultimately serve as a flagship program for national replicability.

Choice as a Motivator

Before students directly admitted to the e+ program arrived on-campus, we surveyed them about whether a customizable engineering degree influenced their decisions to apply to engineering. In the fall 2014 cohort, 75% of respondents agreed or strongly agreed that having the customizable degree influenced the decision to apply while 68% agreed in the 2015 cohort (with 30% strongly agreeing). Despite the advisor's impression of some students arriving to e+ more by happenstance and confusion with the open-option program, these numbers indicate that some direct-matriculation students specifically applied to the college of engineering because of the *Engineering Plus* program and the curricular customization it provides. As one student stated, "I like how it's kind of, you are able to kind of customize it in terms of what exactly you're trying to get out of it." Another student said, "Being able to take classes outside of engineering… I just recognized that there was more skills I wanted to come away with than just my engineering skill set."

Conclusion

Providing expanded course choice is messy from a program administration standpoint, both in terms of the diverse advising it necessitates and the fluid student pathways it encourages and enables. Our early program findings suggest that students are using *Engineering Plus* differently than traditional discipline-based engineering programs and that it is serving them differently. In some cases first-year students arrived to the program thinking they wanted the expanded academic exploration opportunities it provides and later found their passions in more traditional engineering fields, and were thus willing to forego the course choice opportunities. For other students, e+ provided an academic refuge in the college, a place where it is possible to pursue engineering alongside expanded academic exploration in other pursuits. Our findings make it clear that many students disenchanted with traditional engineering programs are making their way to the e+ program where they find a renewed commitment to persist in engineering.

We predict that the *Engineering Plus* program will serve a critical role in the engineering college's retention strategy by serving students who are interested in engineering but for whom a

traditional engineering program—with minimal course choice and quite limited non-technical opportunities—is a poor match, offering them the opportunity to customize their engineering curricula to optimize personal satisfaction and fulfillment.

We also anticipate that engineering students will find logistical relief in the reduced time (and therefore cost) to graduation that the e+ program provides through the strategic use of free electives that count towards their degrees. And, as program marketing improves and a sound reputation for the value of a multidisciplinary, design-based degree is established, we hope to begin seeing e+ become a destination for non-engineering students to migrate into engineering—such as a student initially majoring in environmental studies, who is not put off by the math requirements, finding her or his way to the e+ program's environmental engineering emphasis, coupled perhaps with an environmental policy concentration. We also anticipate broad impact as the e+ program serves society at large by preparing some graduates with deep engineering and math or science content knowledge, pedagogy and *way of thinking* so they are ready to lead in the middle or high school teaching workforce.

The *Engineering Plus* program is young and the program's initial name, which implied lack of depth in content, was a misfire. But the overall program design, a product of extensive benchmarking and imagining a different and expanded role for engineering education in an increasingly complex, technological, global and human-centered world, is holding great promise. Would our college do it over again? Most certainly. Will we make more mistakes? We hope so, as we are taking risks and stretching to find ways to make engineering and *design-thinking* a more relevant part of the core education of many more students. We are evidence-driven in all we do, and constantly "spin the flywheel" for evidence-based program improvements.

The initial small size of the e+ program does not yet generate the numbers to quantifiably impact the college-level retention data; however, individual students matriculating through e+ are unequivocally realizing tangible impacts. Here we circle back to a conundrum of engineering education research: sometimes the greatest impacts are quiet, but immensely life-changing. And some profound impacts surely cannot be captured at all. So, we return to the story of the inaugural fall 2015 *Engineering Plus* graduate—who dug herself out from academic ruin (and misery) in chemical engineering to find herself on-stage at graduation receiving a dean's award. Her joy and reignited passion for engineering are unbridled—a measure of the earnest impact that a second (and different) opportunity through a non-traditional engineering pathway afforded her.

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References

1 Ohland, M.W., Sheppard, S.D., Lichtenstein, G., Eris, O., Chachra, D., & Layton, R.A. (2008). Persistence, engagement, and migration in engineering. *Journal of Engineering Education 97*(3), 259-278.

2 Nixon, W.A., Ettema, R., Holly, F.M., Jr., and Stoner, J.W. (2003). *A Flexible Undergraduate Civil Engineering Curriculum*. Proceedings, *ASEE Annual Conference & Exposition*, Nashville, TN, June.

3 Schell, W.J., IV, Claudio, D., Sobek, D.K., II, Stanley, L., and Ward, N. (2014). *Introducing Flexibility in an Engineering Curriculum through Student-Designed Elective Programs*. Proceedings, *ASEE Annual Conference & Exposition*, Indianapolis, IN, June.

4 Sorby, S.A. (2003). *An Accredited Engineering Degree Program with Flexibility Designed for Student-Centered Learning*. Proceedings, *ASEE Annual Conference & Exposition*, Nashville, TN, June.

5 Wankat, P. and Haghighi, K. (2009). *Multidisciplinary Engineering: Flexibility and ABET Accreditation*. Proceedings, *ASEE Annual Conference & Exposition*, Austin, TX, June.

6 Forbes, M.H., Bielefeldt, A.R., and Sullivan, J.F. (2015). *The Choice Opportunity Disparity: Exploring Curricular Choice Opportunities for Engineering vs. Non-Engineering Majors*. Proceedings, *ASEE Annual Conference & Exposition*, Seattle, WA, June.

7 Forbes, M.H. (2015). *Course Choice Opportunity and Technical-Non-Technical Balance in Undergraduate Engineering Education.* Doctoral dissertation, University of Colorado Boulder.

8 National Academy of Engineering and National Research Council. (2009). *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*. Washington, DC: The National Academies Press.

9 Zarske, M.S., Cunitz, J.L., Forbes, M.H., and Sullivan, J.F. (2015). *Engineering Plus: Creating Community in a Flexible yet Technical Engineering Degree*. Proceedings, *ASEE Annual Conference & Exposition*, Seattle, WA, June.

Appendix A: Fall 2014 Focus Group Questions

- Why did you choose [*Engineering Plus*] over another engineering degree program at (insert university name here) such as mechanical, civil, aerospace, etc.?
- How do you feel about the [e+] curricula?
- What have you done with other people in [e+]?
- How would you describe the [e+] major and people? What's the feeling you get from it?
- Do you think there are any differences between [e+] and other engineering majors overall?
- Are you interested in pursuing any interests outside of engineering during college? Why and how?

Appendix B: *Engineering Plus* Concentrations

Applied Mathematics Minor
Applied Mathematics in Statistics
Business
Economics
Engineering Management
Engineering Physics
Entrepreneurship
Environmental Policy
Environmental Studio Design
Geological Sciences
Pre-Medical
Russian Culture
Spanish and Latin American Cultures
Sustainability
Technology Arts & Media
CU Teach Engineering Math
CU Teach Engineering Science

Note: Students may also propose new concentrations of their choosing. All concentrations are subject to program approval.