The Challenges of Developing Engineering Management and Leadership Curriculum for Students Planning RIPE Careers.

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Proposed ASEE LEAD Track: **Work in progress**

Increasingly, engineering leadership and programs are seeing broad ranges of students interested in pursuing grand challenge and blue-sky type opportunities to 'change the world.' Many of these students lack the confidence and skillsets to lead the teams and organizations that must execute the complex and often-large project work of technology research, management, and/or development. Students who possess the ability to solve technical problems, manage budgets, and apply basic business principles in an effort to develop a product or solution may become adept engineering managers. However, students who can inspire a team to complete and deploy products and solutions so that the whole team's productivity is greater than the sum of the expertise of each individual team member can become engineering *leaders*. Engineering leadership programs at research universities often have the challenging problem of developing curriculum for students who may need, yet not see the value of, leadership education. Further, engineering students who pursue careers outside of the mainstream engineering industry pathways, such as research or entrepreneurship, often do not automatically see the value in leadership and management training in college; they perceive these programs to be aimed just at careers in industry. Therefore, the *objective* of this paper is to introduce the approach that one university is employing to revamp and develop a new credentialed curriculum in engineering leadership aimed at students with broad career interests. There are two facets of this new certificate program, and it aims to create a compelling experience that attracts an increasing number of engineering undergraduates over the next decade. First, the program will provide a rich, focused suite of fundamental engineering leadership development courses. The second facet of the certificate requires each student to choose one of four career directions he/she is likely to pursue after graduation. These are Research, Industry, Pathways that are non-engineering, and Entrepreneurship (RIPE). The efforts to design this new curriculum and revamp our program will be presented, along with the challenges that have emerged to date.

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Background

The Rice Center for Engineering Leadership (RCEL), within the Rice University School of engineering, launched its initial phase (herein referred to as "RCEL 1.0") of engineering leadership certificate classes for undergraduates in 2013. Students took a series of curricular and co-curricular (e.g., an internship practicum, team-building activities, leadership development planning, senior presentation, etc.) classes within this school of engineering certificate program, and the first certified students graduated in 2015. The core competencies, or domain-level learning objectives, for this initial program were for students to acquire leadership, management, and interpersonal skills. The core competencies were woven into the 10-credit hour, four-year certificate's suite of courses. The courses were as shown in Table 1.

Table 1: Course curriculum for RCEL 1.0 of the engineering leadership certificate program.

Courses	**Course summary**
ENGI 140: Engineering Leadership Development	Introduces students to engineering leadership and RCEL's skill and competency domains
ENGI 218/219: Leadership Labs 1 & 2	Course sequence provides hands-on application of leadership skills and techniques in practical situations
ENGI 241: Professional Excellence for Engineers	Practicum course provides guided career and professional development as students participate in 'real-world' industrial, research, or other professional internships
ENGI 315: Leading Teams and Innovation	Reviews and develops skills needed to effectively launch, develop, and lead innovative engineering teams
ENGI 317: Leadership Action Learning	Applies skills students acquire through certificate courses to specific leadership development projects
Courses at the 100 level are for freshman, 200 and 300 level courses are typically for sophomores, and juniors, and 300 level are for juniors. ENGI is the course code for general engineering courses that reside outside of the major engineering departments at Rice University.	

Introduction

A broader engineering leadership curriculum for the 21st century student. Center leadership did an internal assessment of RCEL by surveying its faculty, staff, student participants, and other stakeholders, such as the university's engineering alumni, collaborating faculty, department chairs, associate deans, and dean. The goal of this survey [1] was to identify gaps between the mission of RCEL and the perception of the faculty. The questions allowed stakeholders to return essay responses about the strengths, weaknesses, opportunities, and threats (SWOT) to RCEL flourishing. The survey also helped RCEL leadership assess whether or not RCEL's impact was pervasive and inclusive of the diverse career plans of the students. The key lessons gleaned from the survey were three-prong: (i) RCEL needed to expand its training curriculum to match the diverse career interests of its students following graduation; (ii) RCEL needed to not solely focus on enabling its students to achieve management roles in the first 5 years, but it needed to cultivate a long-term organization-leading leadership mentality as well; (iii) RCEL needed to ensure that the school's engineering faculty viewed RCEL's students as attractive candidates to participate in the various academic endeavors they valued (e.g., research, R&D competitions, society leadership, fellowship competitions, technical conference presenting, etc.). Additionally, a study of the participant numbers revealed that the number and quality of students from various engineering departments correspond with the presence of faculty champions in that department. Career center data at the authors' university showed that approximately 25 percent of the engineering BS/BA students will go to graduate (e.g., engineering MS/PhD) or professional school (e.g., law, business, or medicine). Therefore, RCEL decided to broaden its leadership training to accommodate students who chose career tracks outside of engineering industrial sectors.

RCEL's engineering leadership certificate program aims not only to prepare undergraduate engineering students to become managers and leaders of teams in the first years of their careers, but also to inspire them to ultimately chart a path toward becoming leaders at the top of organizations. There are two facets of the revamped RCEL 2.0 certificate experience that will enable this. First, RCEL 2.0 will still offer a rich, focused suite of fundamental engineering leadership development courses. A major addition to the fundamental leadership curriculum that was not in the prior one is the inclusion of new competencies in project management and engineering ethics [2].

The second facet of the certificate will require each student to choose one of four career directions he/she is likely to pursue after graduating from the university. These are Research, Industry, Pathways that are non-engineering, and Entrepreneurship. These career directions are called "RIPE," an acronym that is a play on a word that represents our goal for RCEL to help engineering students progress from immaturity to maturity in terms of leadership and management preparation. It is RCEL's strategy that by allowing students to apply the fundamental leadership course principles in the short-term and long-term context of their chosen RIPE career paths, the students will be more likely to graduate with a mission-minded drive to progress into leadership. The hope is that they will begin to agree that ethical, technical leadership is key for an organization to flourish. Thus, they will see themselves as the leaders who must excel in their career endeavors in

such a manner that they purposefully rise into leadership in order to more effectively influence the companies and institutions they join.

. Each individual career track in RIPE is explained below:

- **Research (R)**—Students who choose this direction might pursue a doctorate degree [3] in engineering [4] and then become a university professor or a researcher at a Fortune 500 company or a government lab in the near term;
- **Industry (I)**—In the industry career direction, which is the most traditional path, graduates might enter an engineering rotational program at a major technology company and then go into management, ultimately leading and managing large groups and becoming a divisional leader.
- **Pathways that are non-engineering (P) [5]** —Increasingly, we are seeing professional graduate schools aggressively recruit our engineering students to enter careers such as those in law, business, or medicine. Since nearly all industries are increasingly becoming data driven, the value of the analytical, quantitative thinker and leader is going to continue to skyrocket [6]. In addition, programs such as ours must equip its students to carry their objective, data-driven academic training [7] forward to lead this new world.
- **Entrepreneurship (E)**—Some of our students will go on to both start and lead companies, and RCEL plans to enable these young people to do this with as few degrees of separation [8] between technology idea initiation and technology deployment. The plan is to expand the university's offerings in technology entrepreneurship so that students are ready to launch companies formed around their own ideas.

<u>We have formulated three key questions in the ongoing effort:</u>

1.) What are the domain objectives required to capture the core 21st century engineering leadership fundamentals?
2.) What course offerings best excite students to gain an education in engineering leadership, while capturing the domain objectives?
3.) Similar to the program's initial phase of progress (i.e., RCEL 1.0), what metrics should be used to determine the effectiveness of the RIPE career path courses?

The answers to these questions are not known and are therefore a work in progress. However, the methods the RCEL team utilized to develop this new highly integrated curriculum in engineering leadership and management are described below. The methods for initiating the development of RIPE courses will also be discussed.

Methods

Assessing the effectiveness of the RCEL 1.0 certificate. A survey assessment, which allows RCEL 1.0 students to self-report confidence levels in various leadership scenarios, was adopted from an instrument developed by MIT [9], and data for our university is shown in Fig. 1. As seen in Fig. 1, the assessment, which has been used for several years at RCEL, is comprised of a survey of questions to two groups of engineering seniors. The first group are the seniors who completed the RCEL 1.0 certificate program (referred to as "Center" in Fig. 1), while the control group was the engineering seniors who did not participate in it. The confidence rating type instrument was chosen because confidence itself is considered a positive attribute for leaders. Although not rigorously validated by RCEL, the instrument has been successfully used by the Gordon-MIT leadership program, which is nearly 5 years older than RCEL.

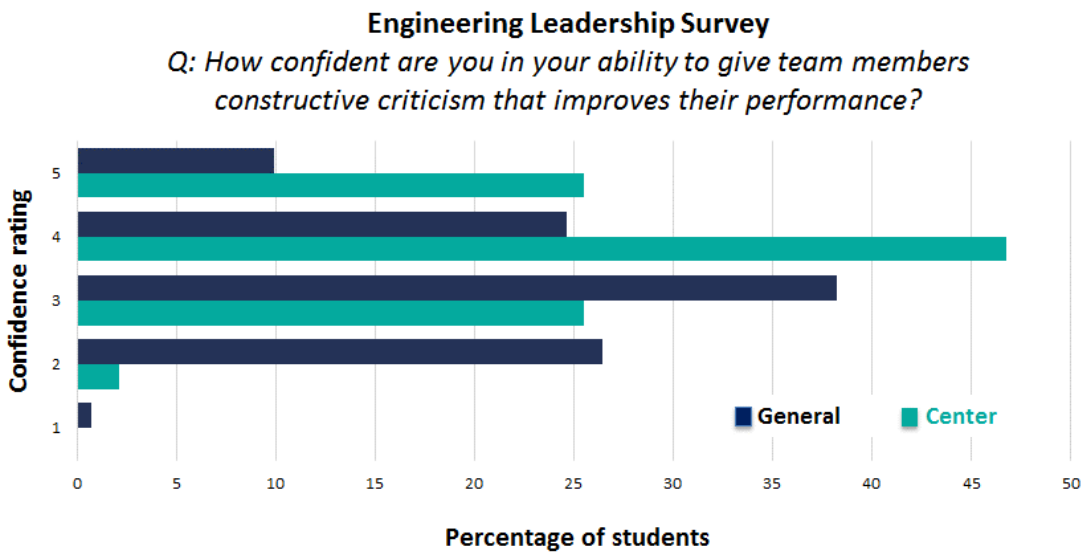
In Fig. 1, the confidence ratings shown in the y-axis are as follows: 1-Not confident, 2-Not very confident, 3-Confident, 4-Very confident, 5-Highly confident. In Fig. 1A, 20 percent more of RCEL students compared to the control group consider themselves 'very confident' about giving constructive criticism to team members to improve their performance. Providing feedback to team members is fundamental to the success for leaders in developing their teams. This skill requires effective use of supportive communication, conflict resolution, and creative problem solving skills to create win-win options in coaching team members.

Figure 1B shows that RCEL 1.0 students were also 5 percent more likely to feel 'very confident' about assuming leadership of a slow-starting project compared to the general engineering population. Knowing when to assert power and influence in a team setting is an element of emotional intelligence. This skill helps anyone emerge as a leader when the needs of the team require someone to take the initiative to address team challenges and drive toward delivering a positive result.

Figure 1C indicates that RCEL 1.0 certificate students are over 20 percent more likely to be 'very confident' in their ability to motivate their team of peers to complete a project. Exercising power and influence appropriately requires the application of rewards and punishments to address behavior and performance issues. Using both extrinsic and intrinsic rewards well can have a dramatic impact on improving motivation, performance, and job satisfaction in teams.

Figure 1D highlights one of the most polarizing differences between RCEL 1.0 certificate students and non-RCEL certificate engineering students. The RCEL 1.0 students are 35% more likely to be 'very confident' in their ability to secure the necessary resources for the team to achieve its goal. One of the key factors that influences team effectiveness is the availability of adequate resources to accomplish team goals. An effective leader quickly identifies needed resources and takes prompt action to make sure resources are available to the team. The leader who can do this effectively, places her/his team in a position to avoid delays and sustain a high level of performance.

Finally, Fig. 1E indicates that over 15 percent more of the RCEL 1.0 certificate students feel 'very confident' they can make firm decisions with limited information. Confidence self-evaluations were also reported as useful in Ahn et al. [10].



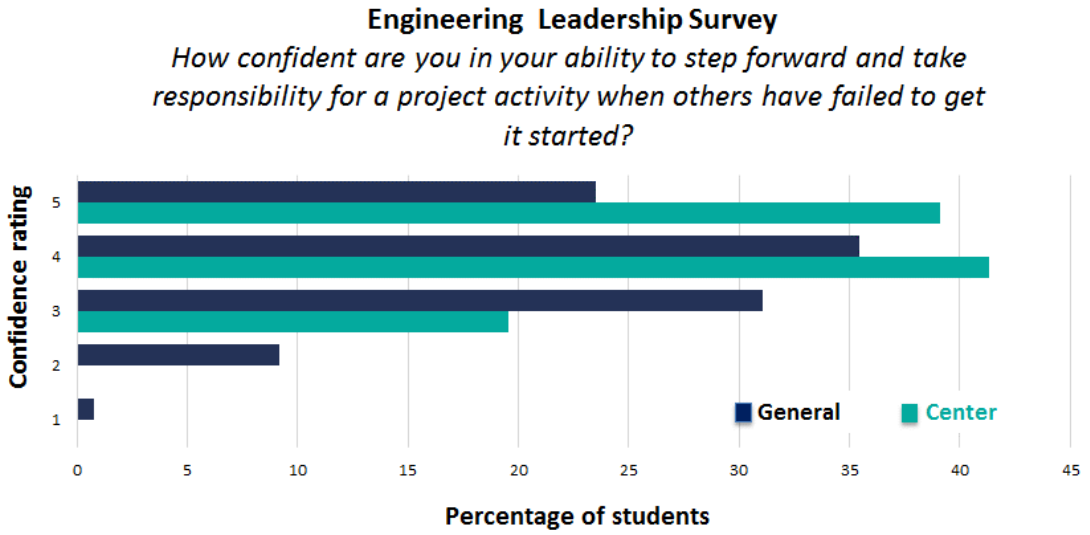
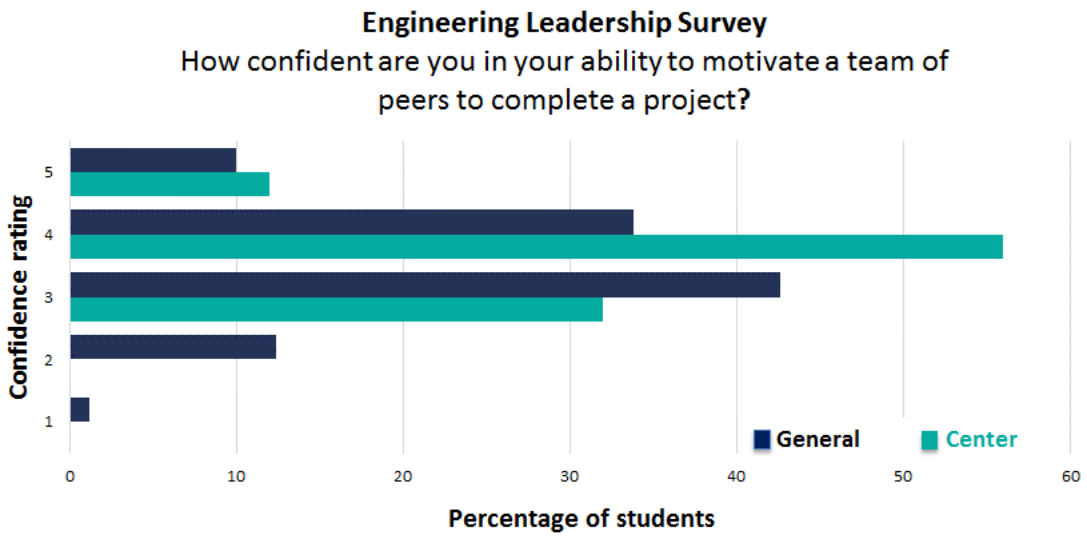


Figure 1A, B: Percentage of students vs. Confidence level pertaining to the question, for the students not in the RCEL (referred to as "**Center**" in figure) certificate program.

Confidence ratings: 1-Not confident, 2-Not very confident, 3-Confident, 4-Very confident, 5-Highly confident



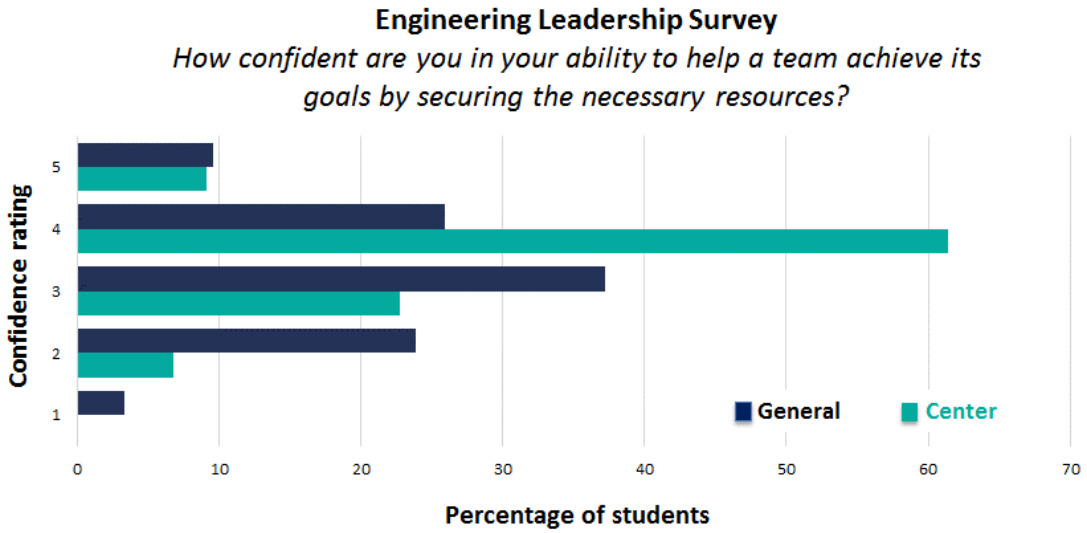


Figure 1C, D: Percentage of students vs. Confidence level pertaining to the question, for the students not in the engineering leadership 'Center' certificate program.

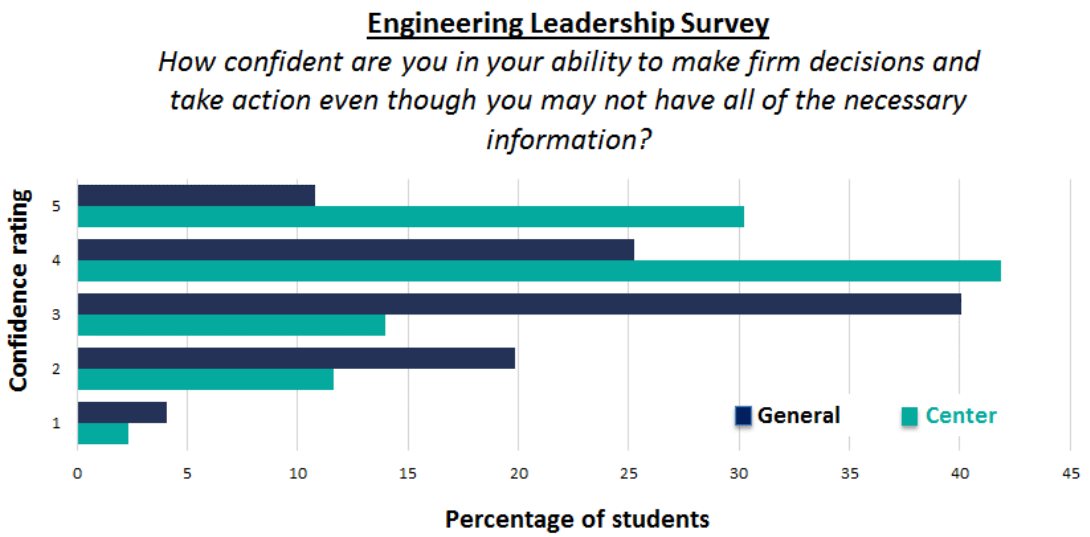


Figure 1E: Percentage of students vs. Confidence level pertaining to the question, for the students not in the engineering leadership 'Center' certificate program.

The data indicates that the RCEL 1.0 certificate program was effective in ensuring that its students were on average much more confident in their leadership mindset. The problem is that the program was predominantly set up to train engineering students going to traditional jobs in the engineering industrial sector. Therefore, a revamped curriculum and approach, "RCEL 2.0", has been proposed to more broadly cover the diversity of career paths that students choose beyond college. Further, revamping the curriculum presents some new opportunities to design every course for maximum synergy and alignment with each other. Core competencies, or domain objectives, can be established a priori, and then interwoven into the curriculum.

The revamped certificate: RCEL 2.0. A team of faculty and staff from RCEL took a holistic look at establishing domain level learning objectives for 21st century engineering leaders and managers. The group, which comprises numerous professors in the practice (each former vice-presidents at engineering companies), communications experts, military veterans, and leadership professionals, had a series of meetings with thoughtful debate about the core competencies of an engineering leader with strong managerial acumen. Taking into account the literature on engineering leadership and management, the core competencies were distilled into the following eight domain learning objectives:

1. **COMMUNICATE EFFECTIVELY -** Apply effective oral, written, and interpersonal communication strategies. [11]
2. **MAKE TIMELY DECISIONS** – Apply analytical and creative problem solving to deliver timely solutions based on the information at hand. [12]
3. **WORK ON TEAMS** - Understand and analyze team dynamics to empower those around them to be successful in accomplishing team goals. [13]
4. **MANAGE PROJECTS** - Demonstrate knowledge of the basic tools and techniques to deliver projects on time, on budget, and within scope. [14]
5. **SELF-LEAD -** Develop self-awareness to build personal mastery, exhibit discipline, and make conscious self-improvement. [15]
6. **CREATE A VISION -** Develop a clear vision that sets future personal and team direction. [16]
7. **APPLY ETHICS and ANALYZE VALUES –** Analyze personal and organizational values and apply ethics concepts to his/her decision-making. [17]
8. **JUMP START THE NEXT STEP** – Demonstrate leadership concepts in at least one specialization: Research, Industry, Pathways to non-Engineering careers, Entrepreneurship (RIPE).

The group had to determine how in-depth instructors should cover these domain-learning objectives in the certificate courses. The method that best achieved this was to employ Bloom's taxonomy [18], shown in Fig 2.

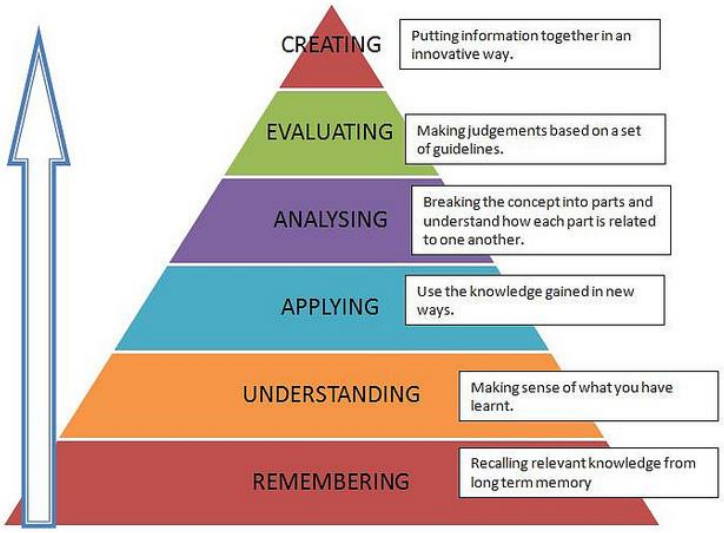


Figure 2: Bloom's taxonomy pyramid with explanatory captions from the less in-depth learning level of "remembering" to the more expert level of "creating".

This hierarchy, arranged in order of increasing skill level from bottom to top, provided a common understanding for assessing the desired student outcomes. Difficulties were encountered when the group realized its ambitions exceeded its ability to deliver. With a certificate program consisting of ten or eleven credit hours, it is not possible to take students, even if they are experienced leaders, from the bottom to the top levels of the scale across all of the competencies in the certificate framework. Therefore, the group prioritized and conceded that mid-range within the hierarchy might be the best that could be done within our constraints.

An integrated curriculum. Mindful of the desired outcomes, the group chose to introduce topics in the early courses, develop them in successive courses, and then assess them during a capstone experience. The plan consists of a main component containing the leadership lecture and laboratory courses taken in a prescribed order (different from the past), culminating in the RIPE specialization course of the student's choice. In parallel, students will participate in experiential learning opportunities, including coaching other students and participating in an internship. Finally, they will learn the basic tools of project management. The following steps describe the determined flow of the curriculum:

- Building self-awareness through assessments and personal reflection
- Developing self-mastery through improved personal behavior modification to prioritize activities and set personal goals as well as building supportive communication skills
- Growing followership and teamwork skills by working in small teams
- Growing larger team leadership, innovation and organizational skills
- Developing a sound understanding of the principles and practices of project management
- Completing a personal vision through a RIPE specialization experience

In between developing the course syllabi and developing the course materials, the group did a macro-scale check of the domain level objectives, namely whether or not the new courses incorporated them in their design. An abbreviated version (e.g., only three courses, and no more than four components are shown) of the much larger matrix is shown in Table 2.

Table 2: Domain level objective and core competency course check table.

Competencies/Domain Objectives	Components	LEAD 100	LEAD 200	LEAD 300
1. **Communicate Effectively** –Apply effective oral, written, and interpersonal communication strategies.	· Identify the purpose, audience, and context for all communications	x		
	· Develop an overall communication plan for each given situation	x	x	
	· Choose an effective organizing structure for maximum message clarity		x	x
	· Produce clear, evidence-based, ethical arguments	x		
2. **Make Timely Decisions** –Apply analytical and creative problem solving to deliver timely solutions based on the information at hand.	· Apply analytical and creative problem solving	x	x	
	· Analyze analytical and creative problem solving approaches	x		x
	· Understand common decision tools	x	x	x

As can be seen in the first column of domain objectives, the group worked to ensure that each competency would achieve at least an "Understanding" level of skill. Subsequent courses would build on that level through more advanced experiential learning activities, including working in teams, participation in student organizations, and internships. Interwoven throughout will be opportunities for students to use their skills in coaching others in a leadership laboratory setting. The result was a much more cohesive and synchronized course structure that captured the best aspects of the prior curriculum while streamlining the flow through elimination of redundancy. A six-course structure was created consisting of eleven credit hours of academic work. A non-credit internship was retained, and the RIPE specialization and project management courses were added. To make it easy for engineering students to identify which engineering courses were leadership based while making our center identity distinct, the new courses will bear the name "RCEL" (e.g., RCEL 100). The course structure and course names are shown in Fig. 3.

Infusion of engineering management into the curriculum. RCEL's curriculum development has been focused on giving its students the skills required to lead and manage a diverse engineering team in multiple environments including research, industry, and as an entrepreneur. Development of these skills will be spread across multiple courses on teamwork, enterprise level leadership and project management. Each course will instruct the student in the art of leading and managing engineering efforts. The professors in the practice, who were all high-ranking managers at engineering and technology companies, will continue to provide RCEL students with a wide range of experiential narratives about managing teams, divisions, and organizations.

- RCEL 100 - Self-Awareness and the Engineering Leader (2 hours)
- RCEL 200 - Personal Development of the Engineering Leader (2 hours)
- RCEL 300 - Development of High Performing Engineering Teams (2 hours)
- RCEL 400 - Leading High Performing Engineering Teams (2hours)
- RCEL 450 – Project Management and Leadership (2 hours)
- One of the following courses
    - RCEL 410 - Engineering Launch Pad – Research (1 hour)
    - RCEL 420 - Engineering Launch Pad – Industry (1 hour)
    - RCEL 430 - Engineering Launch Pad – Alternative Pathways (1 hour)
    - RCEL 440 - Engineering Launch Pad – Entrepreneurship (1 hour)

Figure 3: Names of the required courses in the certificate program

Description of the new RCEL courses.

RCEL 100: Self-Awareness & the Engineering Leader (2 credits)
The purpose of this course is to prepare students to become future engineering leaders. Engineering leadership is an emerging innovation in both education and practice, and our course will prepare students to begin their development journey toward this end. The course is a front-end requirement for RCEL's engineering leadership certificate and premised on the assumption that leadership is an activity that can be learned.

RCEL 200: Personal Development for the Engineering Leader (2 credits - Pre-Requisite: RCEL 100)
The purpose of this course is to prepare students to become future engineering leaders. Engineering leadership is an emerging innovation in both education and practice and our course will prepare students to begin their development journey toward this end. This is the second half of the initial RCEL leadership course (RCEL 100).

RCEL 241: Engineering Internship Practicum (0 credits)
Applied practicum and internship course that provides guided career and professional development for engineering students in a real-world industrial, academic, research, or other professional context. Prepares students to assimilate quickly and to exceed employer expectations during their internships.

RCEL 300: Development of High Performing Engineering Teams (2 credits - Pre-Requisite: RCEL 200)
The purpose of this course is to prepare students for engineering leadership and followership roles in engineering contexts. Topics include mobilizing and launching high performing teams, conducting technical meetings, creating a motivating environment, effective conflict resolution and engineering decision making. This course is required for our school's certificate in engineering leadership and includes a focus on practical skills and how these skills can be learned, developed, and applied in team situations.

RCEL 400: Leading High Performing Engineering Teams (2 credits - Pre-Requisite: RCEL 300)

This course develops skills that are required for enterprise wide technical and engineering leadership positions. Topics include: managing and leveraging diversity, creative problem solving through intersectional thinking, ethical issue identification and resolution, risk management, performance management, development and communication of an enterprise-wide vision, and development of a change management plan.

RCEL 450: Project Management & Leadership Action Learning (2 credits)
This course provides instruction on the tools, techniques, and leadership characteristics required to successfully execute a project. The course addresses the phases of project execution—initiating, planning, executing, monitoring and controlling, and closing as part of the project. The course also offers a practicum experience that allows students to practice leadership skills in an applied

context. In addition to facilitating the technical, management, and/or logistical requirements of the assigned leadership role, each student will participate in an individualized action learning-based model of leadership development, through which he or she must implement a strategic development plan that focuses on one or more designated *areas of potential growth.*

Students must select one the four RIPE courses below *(1 credit):*

RCEL 410 Engineering Launchpad - *Research*

RCEL 410 is one of four RCEL courses intended to jump-start the next steps for aspiring engineering leaders. The other courses deal with industry, alternative pathways, and entrepreneurship, while RCEL 410 is focused on developing an understanding of leadership principles applicable in a research environment. Students will gain insights into managing ethical dilemmas, developing communication strategies, creating a vision and goals, and project management in either an undergraduate or graduate student level engineering discipline. Research in academia, government labs, and industry will be compared and contrasted.

RCEL 420 Engineering Launchpad – *Industry*

The purpose of this course is to prepare students for engineering leadership and followership roles in an industry context. This course is required for our school's certificate in engineering leadership and includes a focus on the practical skills needed to thrive in an industry environment.

RCEL 430 Engineering Launchpad – *Pathways*

Engineering students explore alternative professional paths, including policy, law, medicine, industry consulting, and other viable career options beyond industry and research. Students will identify a focus career track and complete a series of assignments designed to increase familiarity and competency in that discipline.

RCEL 440 Engineering Launchpad - *Entrepreneurship*.

In the past, entrepreneurs were taught to make a business plan and pitch it to investors, but research has shown that 95 percent of all new ventures fail because they have a lack of customers. Further, engineering entrepreneurs often focus mainly on the technological issues before they know what market exists for the technology. This course will focus on identifying the value proposition a potential venture has for a specific customer segment, and who those customers are and why. Students will be forced to "get out of the building" and interview potential customers to help refine their assumptions based on data. The goal is to help student teams create a scalable and repeatable business model.

Discussion: Programming key challenges and proposed solutions

Since only the first of the courses have been launched (e.g., RCEL 100), this effort remains a "Work in Progress" until the first set of students graduate from the RCEL 2.0 degree certificate. Numerous challenges occurred and solutions to them are either being executed or have been proposed. Some of the key challenges are cited below:

(1) developing a completely integrated curriculum is one of the holy grails of engineering education since real-world problems are not conveniently segregated by topic; however, effective integration is limited by the difficulty of coordinating the concepts across different personnel and courses;
(2) while the new curriculum was designed for the student to progressively learn, a certificate program is typically a secondary priority to students' primary majors which means students may not be able to take the courses in the ideal order;
(3) the non-engineering pathway (P) career tracks (e.g., law, business, and medicine) are outside of the traditional engineering school's offering and so acquiring appropriate instructional personnel to match the fluctuating student interest or demand will be a challenge both logistically and economically.

While solutions to the above three challenges can vary, some of the current ones that RCEL has proposed are now mentioned, respectively. First, in answer to the above challenge 1, develop thorough syllabi and course plans outlining the key objectives of each lecturer and document all course materials in electronic form on course organization platforms (e.g., Canvas, Blackboard). This will also enable modularization where different instructors can either follow the existing lectures, or plug-n-deliver their own within the course objectives. In answer to the second challenge, aspiring programs should establish prerequisites but allow exceptions. Additionally, convey to students what the optimal course path is to finishing the certificate program and how they can maximize its benefits in preparation for their job interviews and career launch. In answer to the third challenge where non-engineering career tracks may have sparse student demand from year to year (e.g., some years may have less engineers who plan to become lawyers than doctors), utilize an independent study model where students attend a single class where the instructor utilizes a semester checklist of approved assignments related to the career track. Local professionals in the areas should be brought to these classes to help design the checklist.

Conclusion

The well-prepared 21st century engineering leader can only emerge from an integrated academic curriculum that is aimed at educating her to apply key leadership skills in whatever career path she chooses. This paper describes the challenges addressed and methods used to undertake the design of an engineering leadership and management curriculum for undergraduates that takes into account both fundamental leadership principles, as well as leadership in research, industry, pathways that are non-engineering, and entrepreneurship. The existing undergraduate certificate program in engineering leadership was first assessed for its effectiveness so that it could serve as a foundation on which to build the new integrated curriculum. Based on the assessment and surveys

of the stakeholders, core leadership competencies (or domain level objectives) were then developed by an experienced instructional team with diverse technical and non-technical experiences and background. Using Bloom's taxonomy as a guiding framework, the team then evaluated each core competency and designated a minimal acceptable standard, in accordance with an attainable mandate for the development of strong foundational leadership skills. Finally, the content of each course is being designed to present key concepts, while integrating these core competencies through multi-faceted learning vehicles, including traditional lectures, case studies, experiential learning assignments, role playing exercises, and a variety of innovative curricular and co-curricular experiences. This paper outlined the methods being used to design the curriculum and introduced the courses that comprise that curriculum.

Further, challenges in developing a new engineering leadership certificate have been cited alongside some of the proposed solutions to them. The goal here is to help aspiring engineering leadership programs understand not just how to design an integrated, career-path-inclusive program, but also to get an idea of some of the challenges in doing so and how to surmount them.

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