The Engineering Mindset Report

A Vision for Change in Undergraduate Engineering and Engineering Technology Education

***Final Draft* report of a national task force organized by the American Society for Engineering Education and National Academy of Engineering with support from the National Science Foundation, Division of Engineering Education and Centers and Directorate for Engineering**

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Engineering Mindset
INCLUSIVE MINDSET FOR THE FUTURE

For more information on the Vision and Change in Undergraduate Engineering and Engineering Technology Education Initiative, see

https://mindset.asee.org/

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ASEE and NAE Report Collaboration

Founded in 1893, the American Society for Engineering Education (ASEE) is a nonprofit organization of individuals and institutions committed to furthering education in engineering and engineering technology. ASEE is the lead organization for this report, an effort that began when Sheryl Sorby was President of ASEE in 2020. Sheryl challenged the profession to review the state of undergraduate engineering and engineering technology education in preparing engineers. A 10-member Steering Committee was formed. With the urging of NSF, the Steering Committee began working with the National Academy of Engineering (NAE). The NAE is a part of the National Academies of Sciences, Engineering, and Medicine, a private, independent, nonprofit institution created by the federal government in 1863 to "provide independent, objective advice to inform policy with evidence, spark progress and innovation, and confront challenging issues for the benefit of society". The mission of the NAE is to "advance the welfare and prosperity of the nation by providing independent advice on matters involving engineering and technology and by promoting a vibrant engineering profession and public appreciation of engineering." The collaboration between ASEE and NAE led to this report with the support of the National Science Foundation (NSF).

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Acknowledgements

With funding from the National Science Foundation (NSF) and support from the American Society for Engineering Education (ASEE) and the National Academy of Engineering (NAE), it was possible to bring together some of the best minds and creative talent to make recommendations to faculty, administration, industry, and funding agencies on new directions for engineering and engineering technology education. We are grateful to NSF with the support of ASEE and NAE for providing an opportunity for faculty education leaders from all types of colleges and universities to engage in conversations and meetings that led to this report and a call to action.

This report is the collective wisdom of more than 100 engineering and engineering technology faculty, industry representatives, accrediting organizations, and students. We express our gratitude and deep appreciation for all those who participated in meetings, discussions, and writing. The spirit of volunteerism was strong and the many hours of meetings, discussing, and writing is a testament to the energy and passion of engineering faculty and our constituents to our profession. This level of commitment leads us to believe that change at the scale recommended in the report is not only possible but probable.

We would like to recognize the work of Sarah DeLeeuw from ASEE and Joanna Livengood from the DOE working in collaboration with the NAE for all their assistance in planning for the meetings. We would like to thank Cameron Fletcher for editing the manuscript and Costa Michailidis, Kyle McCarth, and Hana Mamnoon from KnowInnovation for their work with the virtual convenings. We need to thank and recognize Autodesk, Inc for providing funding to support the work of the writing team.

We hope that this report will become the catalyst necessary to create a movement to advance undergraduate engineering and engineering technology education. The recommendations in this report are a roadmap for faculty to prepare the engineering workforce for the 21st century.

The Engineering Mindset Report - Summary

As a response to major societal challenges during the Cold War era, an influential report was written in 1955 to implement the recommendations of the ASEE Committee on Evaluation of Engineering Education. [This later became known as the "Grinter Report" after Dr. L. E. Grinter, who served as secretary of that ASEE Committee.] [1]

The Grinter Report recommended a shift in the mindset of engineering education that has persisted for nearly 70 years. Specifically, the report recommended that engineering move from an apprentice-based *trade* to a scientifically- and mathematically-oriented *profession*. This shift was viewed as essential in the preparation of engineers to effectively address the new and complex engineering challenges of the time. This mindset shift was widely adopted and remains the dominant way of thinking in engineering and engineering technology education today. Unfortunately, the result of this mindset is an education system based on Industry 2.0, that is no longer suited for our Industry 4.0 world.

Fundamentally unchanged since 1955, our current mindset in engineering education is widely defined by the following characteristics:

- A weed-out mentality that excludes vast proportions of our society at a time when the need for engineering talent and diversity of thought is more critical than ever.
- A focus on introductory courses in mathematics and science, especially calculus, is the foundation of *all* engineering and is viewed as a proxy for engineering student talent.
- An emphasis on technical competency and monetary profits, rather than human impacts and social good.
- An education system that is inflexible, uninspiring, unwelcoming, and unattractive to many segments of our diverse population, despite research that shows the power and innovation that stems from diverse ways of knowing.
- A reliance on professors who lecture *at* their students, despite extensive scholarship on the merits of student-centered, active learning pedagogies,

We are at a crossroads in engineering education, where we can either continue to incrementally improve a system handed to us by our past, or create a movement to design a new system that addresses the challenges we face now and into the future.

[1] Scribd. (n.d.). *The Grinter Report PDF | PDF | Teachers | Engineering*. [online] Available at: https://www.scribd.com/document/190749049/The-Grinter-Report-PDF [Accessed 8 Nov. 2023].

Engineering education stands as a crucial pillar in our technology-driven, innovation-focused economy, playing a pivotal role in shaping our nation's future and societal progress[2]. The escalating global challenges highlighted by the United Nations Sustainable Development Goals and the National Academy of Engineering's Grand Challenges necessitate a transformative approach to preparing engineers. As advanced technologies continually reshape every facet of our lives and societal institutions, there is an urgent need for our education systems, industries, and individuals to adapt to these dynamic changes.

The challenges facing the world urgently require engineers from diverse backgrounds, equipped with technical skills, and perhaps more importantly, a deep understanding of the impact of their work on society and a consideration of ethical, social justice, and sustainability implications. However, the stark reality is that engineering education, primarily tailored to a small subset of the population, falls short in several areas. The Engineering Mindset Report (referred to as the Mindset Report hereafter) scrutinizes the multifaceted challenges, current engineering mindset, and systemic barriers within engineering education that hinder us from achieving our full potential as a profession.

Persistent systemic barriers and racial biases impede the inclusion of underrepresented groups in engineering, diminishing social mobility opportunities. The gender disparity in engineering is alarming, with only a small fraction of engineers and tenured engineering faculty being women, despite increasing numbers of women seeking degrees in higher education. Traditional educational models, often institution-centric and rooted in outdated learning theories, fail to foster flexibility, creativity, and inclusivity, thus limiting student interest and potential. Engineering curricula and pedagogical approaches still largely reflect an antiquated mindset, misaligned with the rapidly evolving digital world.

Some of the challenges we face are being addressed and, in some cases, have been addressed for decades with mixed results. We are making incremental, linear improvements in a world that is changing exponentially. We use teaching methods and practices based on an outdated analog education system to prepare engineers for the challenges of a rapidly developing digital world. We attempt to catch up using gradual change when a step function change is required. An inclusive racial and gender-balanced profession will allow us to realize the full human potential to solve these massive systemic challenges.

The world's challenges today demand systemic change and a growth mindset in engineering education and of practicing engineers. The rich history of the nation's engineers' extraordinary accomplishments brings hope that today's challenges for humanity can be addressed with systemic changes in engineering education based on a growth mindset. This approach builds on the scientific and analytical mindset of our current system and modernizes it to include effective student-centered practices. The engineering mindset needed in the digital age fundamentally differs from when the Grinter Report was written. Despite many subsequent reports, engineering education has failed to *substantially* change its educational practice and mindset and fails miserably in most measures of diversity and access.

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[2] The Mindset Report uses engineering education in the text even though it is inclusive of both BS undergraduate engineering and engineering technology programs and curricula. The report addresses the current state of engineering education found at most institutions of higher education but recognizes that there are some programs that have already successfully implemented significant changes aligned with the recommendations in the Mindset Report.

Using a threefold framework as a guide, the report looks at undergraduate education in the context of:

1.) addressing the challenges facing humanity in the 21st century,
2.) increasing access to and diversity of the engineering profession, and
3.) developing a student-centric growth mindset in the preparation of engineers.

The American Society for Engineering Education (ASEE) and the National Academy of Engineering (NAE), through the support of the National Science Foundation (NSF) have undertaken the task of reviewing the current state of engineering and engineering technology education to make recommendations that will create a **movement** to advance engineering.

> We are at a crossroads in engineering education, and frankly throughout all of higher education, where we can either continue to incrementally improve a system handed to us by our past or design a new system that addresses the challenges we face. We need a **shared commitment through a movement** to create a new future for engineering education in our nation**.** We call for conditions in which engineering education programs can invent and demonstrate **new teaching and learning systems** where we admit a more inclusive and diverse student population and **realize the full potential of every student.** The challenges society and humanity face require the contribution of every person. It requires an engineering education system that **leads to self-directed and lifelong learners** who can collaborate, solve problems, and communicate in varied contexts and with people from varied backgrounds and life experiences.

Our current highly standardized higher education system was created to prepare graduates for a world of predictable jobs, stable careers, and homogeneous cultures. It is no longer acceptable for the vital engineering discipline to rely on standardized test scores and uneven K-12 experiences to serve as an arbitrary means of sorting human potential. It is also unreasonable to expect even the most dedicated engineering educators and leaders to move beyond incremental improvements within the constraints of an outdated system.

Furthermore, an engineering education system perpetuating and reinforcing inequitable opportunities and outcomes is intolerable. The present state of engineering education across almost every dimension reveals that there are unacceptable gaps that persist along the lines of race, family income, gender, disability, and the LGBTQIA community. [3]

Our democracy, economic competitiveness, national security, and ability to address humanity's grand challenges rest in large part on an engineering education system that is inclusive, dynamic, and learner-centered in service of a more promising and sustainable future. Our engineering education system must be transformed to rise to this challenge.

Many in engineering education recognize these challenges and have been working towards creative solutions at their respective institutions and through collaboration with others. These efforts can be significantly accelerated if a national initiative provides “wind in their sails”. With this as a backdrop, a diverse group of people interested and dedicated to improving engineering education came together to define this Call to Action and to imagine and make recommendations for a compelling new future for engineering education.

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[3] Cech, E. A. (2022). The intersectional privilege of white able-bodied heterosexual men in STEM. *Science Advances*. https://doi.org/abo1558

The Mindset Report

The Mindset Report is the result of a multi-year effort to guide faculty and leaders through key recommendations for changing the landscape of engineering and engineering technology education to better meet the needs of our ever-changing world.

The report evaluates the current state of engineering education and curricula through the lens of diversity, inclusivity, pathways, and mindset. This evaluation leads to recommendations for change that will have the maximum impact on improving the diversity and inclusivity of the engineering profession and lead to an engineering mindset appropriate for the 21st century. The Mindset Report identifies the most challenging issues and limitations of our current system of preparing engineers. Each challenge and limitation is addressed with specific recommendations for change that will result in the transformational improvement required in the preparation of engineers for today and into the future.

The Task Force led by the Steering Committee's charge developed the findings and actionable recommendations that follow. In some cases, we include examples of where the recommendation has already been successfully implemented. Future phases of this project will include more actionable strategies and a "blueprint" for making the recommended changes possible.

The findings and recommendations in the Mindset Report are clustered around the following six main themes:

1. Create flexible program structures to remove barriers
2. Evidence-based pedagogy: Creating a student-centered engineering education
3. An accessible and diverse engineering education learning environment
4. Preparing campuses for a student-centered engineering education
5. Leveraging strategic partnerships
6. Engineering a new mindset for engineering education

These recommendations will remove barriers to increase access and diversity, improve instruction leading to better student outcomes that will lead to the next level of excellence in undergraduate engineering education. The recommendations found in this report include the following actions.

Create Flexible Program Structures to Remove Barriers

Recommendation 1.1: Instead of a one-size-fits-all all-math requirement in the expected level of incoming math preparation, incorporate in-context mathematics across the introductory curriculum to help alleviate student inequities due to K-12, economic, first-generation, and other differences.

Recommendation 1.2: Modularize the engineering curriculum to allow students to flexibly choose their pathways through fundamental courses and as a means to offer electives on important and emerging topics in engineering and engineering technology.

Recommendation 1.3: Assess for competency (mastery) and employ formative assessments using techniques such as “ungrading” instead of focusing on current grading and assessment practices.

Recommendation 1.4: Assess prerequisites to allow for maximum student flexibility and alternative pathways through the curricula.

Recommendation 1.5: Create student-centered paid internship and co-op programs integrated into engineering curricula that encourage, support, and recognize the value of work experiences.

Recommendation 1.6: Create curricula and support structures that provide more seamless transitions between engineering technology and engineering undergraduate degree programs while ensuring students are prepared with the necessary skills and knowledge to succeed in their chosen field.

Evidence-based Pedagogy: Creating a Student-Centered Engineering Education

Recommendation 2.1: Integrate hands-on and collaborative learning pedagogies that balance student ownership and choice and effectively working with others.

Recommendation 2.2: Implement methods to support learners both in and outside the classroom (e.g. through scaffolding, etc).

Recommendation 2.3: Align time and evaluation with expected outcomes via inclusive assessment practices and continuous formative feedback.

Recommendation 2.4: Engage and support faculty in some form of systematic professional development and evaluation of their educational innovations through scholarly approaches.

Recommendation 2.5: Identify or create digital technology platforms that need to be built to support alternative approaches to learning and evaluation.

An Inclusive and Diverse Engineering Education Learning Environment

Recommendation 3.1: Evaluate the systems in place in our engineering and engineering technology programs and make changes that will create a fair and equitable system for all students.

Recommendation 3.2: Offer professional development on positionality for faculty in order to raise awareness of one's identity and how it influences a person's teaching and everyday interactions.

Recommendation 3.3: Provide professional development for faculty and staff to foster development of a mindset that centers on lifelong learning to support faculty's understanding of inclusive and equitable teaching practices.

Recommendation 3.4: Modify engineering curricula to emphasize a humanized socio-technical framework.

Recommendation 3.5: Expand user-centered design practices common within engineering to a whole student-centered design of learning environments (where whole means students' comprehensive identities and experiences are valued, included, and affirmed).

Preparing Campuses for a Student-Centered Engineering Education

Recommendation 4.1: Revise tenure and promotion processes at the department, college and university levels to reward effort, innovation, and risk-taking in teaching.

Recommendation 4.2: Reimagine institutional policies that support innovation in teaching and learning.

Recommendation 4.3: Revise program accreditation requirements to align with the changing needs of our society.

Recommendation 4.4: Work with and advocate to federal and state governments to increase flexibility in financial aid regulations, including scholarships for year-round and part-time learning.

Recommendation 4.5: Explore and adopt a different paradigm to support an engineering mindset that fosters a culture of accountability in access and diversity.

Recommendation 4.6: Track data that matters.

Leveraging Strategic Partnerships

Recommendation 5.1: Integrate experiential learning for all students in a societal and professional context at the program level.

Recommendation 5.2: Foster partnerships among accreditation agencies, academia, and industry councils that focus on engineering in a societal context.

Recommendation 5.3: Facilitate discussion among ABET, NSPE, and academic institutions regarding the divide between engineering and engineering technology.

Recommendation 5.4: Create a new accreditation option specifically for BS degree programs in engineering technology or modify EAC to include BS engineering technology programs.

Recommendation 5.5: Form strategic partnerships with community colleges to bring about change, especially regarding credit transfer.

Recommendation 5.6: Foster broad collaborations to assist PK-12 educational systems in valuing and championing engineering learning.

Engineering a new mindset for engineering education

Recommendation 6.1: Change the perception of engineering by promoting the idea that engineering is for everyone who wants to be a problem solver, not just those who excel in mathematics.

Recommendation 6.2: Remove artificial barriers to the engineering profession through a design-by-choice flexible engineering curriculum.

By making fundamental changes and modifications to the engineering curricula and institutional structures, leveraging strategic partners in the changes, and assisting faculty, staff, and leadership in developing a student-centered pedagogy and inclusive mindset, barriers will be removed, and student outcomes will improve that will lead to a transformed and inclusive undergraduate engineering education for the 21st century.

CHAPTER 1. Call to Action

Introduction to the Report on Advancing Engineering Education

Engineering education[4] is a crucial pillar in the United States' technology-driven, innovation-focused economy, playing a pivotal role in shaping the country's future and societal progress. The escalating global concerns highlighted by the National Academy of Engineering's Grand Challenges for Engineering[5] and the United Nations Sustainable Development Goals[6] highlight the need for a transformative approach in preparing engineers to address them. As advanced technologies continually reshape every facet of our lives and societal institutions, education systems, industries, and individuals must adapt to these dynamic changes.

The world urgently requires engineers from diverse backgrounds, equipped not only with technical skills but also with a deep understanding of their work's societal and ethical implications. However, the stark reality is that engineering education, primarily tailored to a small subset of the population, falls short in several important ways. This report examines the multifaceted challenges and systemic barriers in engineering education that prevent students, industry, and this country from achieving our full potential.

This report evaluates the current state of undergraduate engineering education curricula through the lens of pathways, mindset, diversity, and inclusivity. This evaluation leads to recommendations for change that will lead to an engineering mindset appropriate for the 21st century and have the maximum impact on improving the diversity and inclusivity of engineering education and the workforce.

Challenges and Barriers

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[4] In this report engineering education is inclusive of undergraduate BS programs and curricula in both engineering and engineering technology. The report addresses the current state of engineering education found at most institutions of higher education but recognizes that there are some programs that have already successfully implemented significant changes aligned with the recommendations in this report.

[5] *Grand Challenges - Grand Challenges for Engineering*. (n.d.). Www.engineeringchallenges.org. https://www.engineeringchallenges.org/

[6] United Nations. (2015). *The 17 sustainable development goals*. United Nations. https://sdgs.un.org/goals

Persistent systemic barriers and racial biases impede the inclusion of underrepresented groups[7] in STEM, diminishing both innovation and social mobility opportunities. The gender disparity in engineering is alarming: despite increasing numbers of women in higher education, only a small fraction of practicing engineers and tenured faculty are women. Often institution-centric and rooted in outdated learning theories, traditional educational models do not foster flexibility, creativity, and inclusivity, thus limiting student potential and access. Engineering curricula and pedagogical approaches still largely reflect an antiquated mindset, misaligned with the rapidly evolving digital world.

Most of these challenges are being addressed, and in some cases, have been addressed for decades, but with mixed results. The improvements are linear in a world that is changing exponentially. Teaching methods and practices based on an outdated analog education system are being used to prepare engineers for a rapidly developing digital world. An inclusive racial and gender-balanced profession will allow us to realize the full human potential to solve these massive system challenges.

This report identifies the most challenging issues and limitations of our current system in preparing engineers. The challenges were identified by practicing engineers and engineering faculty through a process described later in the appendix. Each challenge and limitation is addressed with specific recommendations for change that will result in the transformational improvement required in the preparation of engineers for today and the future.

Framework for the Report

Today's challenges demand systemic change in engineering education and a growth mindset in engineering education and practicing engineers. The rich history of the nation's engineers' extraordinary accomplishments brings hope that today's challenges to humanity can be addressed with systemic changes in engineering education based on a growth mindset in the classroom. This approach builds on the scientific and analytical mindset established by the Grinter Report[8] and modernizes it to include known effective student-centered success practices. The engineering mindset needed in the digital age fundamentally differs from when the Grinter Report was written in 1955. Despite many subsequent reports, engineering education has failed to change its engineering practices and mindset substantially and fails in most measures of diversity and inclusivity.

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[7] In the STEM fields, these individuals have historically been called underrepresented minorities (URMs) in federal datasets and much of the literature, although some researchers and practitioners have suggested other terms to describe this population. As the language used to describe these individuals continues to evolve, this report uses the term "historically minoritized and marginalized racial and ethnic groups" except in direct quotes.

[8] Scribd. (n.d.). *The Grinter Report PDF | PDF | Teachers | Engineering*. [online] Available at: https://www.scribd.com/document/190749049/The-Grinter-Report-PDF [Accessed 8 Nov. 2023].

Using a threefold framework as a guide, the report looks at undergraduate education in the context of:

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The American Society for Engineering Education (ASEE) and the National Academy of Engineering (NAE), with financial support from the National Science Foundation (NSF), have reviewed the current state of engineering and engineering technology education to make recommendations that will advance the preparation for our future engineers.

Shifting the Engineering Mindset

The steering committee adopted the title *Engineering the Inclusive Mindset of the Future* to anchor the efforts of the full task force to take a fresh look at engineering education. "Mindset" refers to established patterns of thinking and includes paying attention, interpreting, feeling, and reasoning, all leading to an individual's actions. Dweck studies why people succeed by examining the self-conceptions (or mindsets) people use to structure the self and guide their behavior. She focuses on a dimension of mindset that ranges from "fixed" to "growth."[9]

Like other fields, engineering comprises people who fit the entire mindset dimension. The ASEE steering committee believes that in the next 50 years, the engineering profession, with its rapidly changing, complex, intertwined, systemic challenges, will need engineers to predominantly have a "growth" mindset. The members also believe that many aspects of engineering education have already developed characteristics of this mindset, which, in some ways, is better than other pre-professional fields of study. Engineering students often address significant challenges and problems and must overcome constraints and obstacles to find solutions. The complexity of challenges can reinforce the value of persistence in effort and the importance of taking feedback constructively. But for too many students, the experience feels more like they are being "weeded out" because they are "not smart enough" to be in engineering.

This report results from a multiyear effort to guide engineering and engineering technology faculty and leaders through specific recommendations for changing curricula, pedagogy, and mindsets.

The report identifies conditions in which engineering education programs can invent and demonstrate new teaching and learning systems, admit and retain a more diverse student population, and realize the full potential of every student. The challenges society and humanity face require the contribution of every person. To achieve this, the engineering education system must develop self-directed and lifelong learners who can collaborate, solve problems in

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[9] Dweck, C.S. 2006. *Mindset: The New Psychology of Success*. Ballantine Books.

a societal context, and communicate in diverse contexts and with people of varied backgrounds and life experiences.

The current US standardized higher education system was created to prepare graduates for a world of predictable jobs, stable careers, and a homogeneous culture. However, it is no longer acceptable for the vital engineering discipline to rely on standardized test scores and uneven K-12 experiences as a means of sorting human potential. It is also unreasonable to expect even the most dedicated engineering educators and leaders to move beyond incremental improvements within the constraints of an outdated system.

Furthermore, an engineering education system perpetuating and reinforcing inequitable opportunities and outcomes is intolerable. In engineering education, across almost every dimension, unacceptable gaps persist along the lines of race, family income, first-generation students, gender, and disability.

Our democracy, economic competitiveness, national security, and ability to address humanity's grand challenges rest in large part on an engineering education system that is inclusive, dynamic, and learner-centered in service of a more promising and sustainable future that serves society. Our engineering education system must be transformed to rise to this challenge. We need to have a mindset and "a belief that excellence and equity are inextricably entwined, such that excellence without equity (privilege reproducing privilege) is not true excellence, and equity (mere access) without excellence is unfulfilled promise."[10]

Many in engineering education recognize these challenges and have been working towards creative solutions at their respective institutions and through collaboration with others. If a national movement provides "winds in their sails," these efforts can significantly accelerate, proliferate and be sustained.

We have yet to fully grasp the far-reaching social, political, and economic changes caused by digitization through computers, algorithms, automation, and artificial intelligence. These are not just new technologies but new ways of being that have so fully transformed the world that it is difficult to fully understand how much we have changed.[11] Engineering education must be transformed from teaching to the test to active learning. Current educational systems that focus on seat time with passive students and rigid requirements need to be replaced. To transform engineering education, we need a **movement** to redesign the curricula, pathways,

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[10] UERU. (n.d.). *Boyer 2030 Commission Report*. [online] Available at: https://ueru.org/boyer2030 [Accessed 25 Jan. 2024].

[11] Davidson, C.N. (2022). *NEW EDUCATION : how to revolutionize the university to prepare students for a world in flux.* S.L.: Basic Books.

requirements, and pedagogy that challenges and empowers students to move beyond workforce readiness to world readiness.

CHAPTER 2. Background & Rationale for the Report

There are a number of factors driving the need for a transformational change in engineering education. This section of the report summarizes the most important drivers of change that lead to what needs to change. There are fundamental drivers related to the economy, national defense and security, rapidly developing technologies, outdated education practices, and failed diversity and inclusivity efforts that are the drivers for change.

Current State of Undergraduate Engineering Education Practice

US institutions have much to be proud of in how they educate engineers. While other fields have only recently discovered the values of high-impact learning experiences[12], many engineering baccalaureate programs have incorporated capstone experiences, and many programs incorporate internships and real-world interactions and designs, team experiences, and the generation of writings and communications related to the field. In addition, for years, engineering educators and administrators have engaged professional societies, industry, government, and academic practitioners in setting minimum educational requirements for accreditation of engineering, engineering technology, and related fields. Although these advances should be recognized, they are very uneven in their implementation and have been added to a flawed curricular and mindset framework that limits their effectiveness. Engineering graduates are highly sought after, but our society and economy need even more engineers to fill our nation's needs.

The United States has a rich history of engineering achievements[13] that have significantly benefited the world, many of them owing to the US engineering education system. It is also important to recognize that some of these remarkable achievements have also resulted in less beneficial (un)intended consequences[14]. The interstate highway system, for example, cuts through the heart of many urban communities; routes were often planned in areas of lower socioeconomic standing, where they worsened air quality, lowered property values, and disrupted the pedestrian landscape. Communities lost churches, green space, and large numbers of homes. They also lost small businesses that provided jobs in areas already struggling from racist zoning policies, disinvestment, and white flight. A more humanized,

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[12] Kuh, George D., and Carol Geary Schneider. *High-Impact Educational Practices: What They Are, Who Has Access to Them, and Why They Matter*. Association of American Colleges and Universities, 2008.

[13] NAE Website. (n.d.). *Great Achievements and Grand Challenges*. [online] Available at: https://www.nae.edu/19579/19582/21020/7326/7461/GreatAchievementsandGrandChallenges.

[14] Cady, B. (2023). *Invisible Bridges: (Un)intended Consequences*. National Academy of Eng

diverse, and ethically-based engineering profession can better predict and mitigate possible unintended consequences.
In these and many other ways, technology drives changes in society, and society poses new opportunities and challenges for technology. Engineering and engineering technology graduates affect the cultural ecosystems in which their systems and devices are deployed. Our current cultural and environmental ecosystems have changed at tremendous rates, and they will continue to change at the same or an even faster pace in the future.

Engineering education has been and remains a foundational discipline for modern society. Although engineering education has evolved over the years, it has rarely achieved more than incremental change as it adjusts to emerging technologies and societal demands. We are currently in one of those rare times that demand transformational change. The extent and pace of change are accelerating, and the rapid evolution of digital and AI technologies requires a transformational change in our education system to meet the needs of future engineers.

Ties to Our Past Creating Barriers for Sustained Improvement

The Foundational Elements of the US Higher Education System

The Second Industrial Revolution (1870–1914) brought significant economic and technological progress, leading to changes in higher education to meet the needs of a transforming society and workforce. The structure of the current higher education system, especially in engineering, originated during this period, designed to transition individuals from agricultural and small shop work to industrial and managerial roles in factories and offices. This “factory model“ of education emphasized specialized, discipline-focused training.

However, subsequent technological shifts—especially the advent of computing and digital technology in the Third Industrial Revolution (which began in the late 1940s), and now the integration of artificial intelligence (AI) in the Fourth Industrial Revolution—call for a major overhaul of the century-old education system. The existing model is characterized by the rigid structure of the credit hour system, which measures time rather than learning, and compartmentalizes education into discipline-specific silos.

The current system is also marked by other dated features such as majors, minors, divisions across disciplines, standardized degree requirements, and various traditional academic and administrative practices. While these elements were innovative and effective at the time of their inception, they are less suited to the educational needs of the 21st century.

For engineering education to evolve, it must confront and transform within the framework of these established systems. Higher education must be reimagined to incorporate current understanding of human learning and be adaptable to the demands of the 4th Industrial Revolution. This involves moving beyond the credit hour to alternative methods of measuring learning and restructuring the system to foster interdisciplinary, flexible, and skill-based education. We have a 2.5 education system in a 4.0 world. We need a transformed education system for our time.

The Foundational Elements of Engineering Education and Our Current Mindset

Historically, the engineering profession in the United States struggled to gain recognition as a profession on par with fields like law, medicine, and science. Initially considered a practical art, engineering gradually evolved into a more scientifically based discipline as various engineering subfields developed. Engineers began using mathematical analysis and controlled experiments, and technical training shifted from apprenticeships to university education.

After World War II, the Cold War rivalry between the United States and the Soviet Union heightened the scientific emphasis on engineering. This transformative period prompted a reevaluation of engineering education by academic institutions.

In 1952, the president of the American Society for Engineering Education (ASEE) formed a committee to assess the state of engineering education in the U.S. The resulting 1955 report, known as the Grinter Report, brought a shift from a predominantly practical, hands-on curriculum to one rooted in theory and engineering science. It made the case that a scientifically oriented engineering curriculum was essential to prepare engineers to address new and complex engineering challenges effectively. This mindset shift was widely adopted and remains the dominant way of thinking in engineering education.

Mathematics as a Requisite Mindset for Engineering

The mindset of the profession after the Grinter Report was based on mathematics and science as the core for engineering education. Mathematics in application areas such as engineering is known as service mathematics,[15] and the focus on mathematics quickly evolved such that calculus became viewed as the "only" mathematics worthy of inclusion in the engineering curriculum. It became a proxy for ability in engineering education: "If you can't master calculus, you can't become an engineer." The engineering profession has long been perceived as difficult and only for students who excel in mathematics and are ready for calculus. This narrow perception creates an artificial barrier to entry into the engineering profession, leading to the exclusion of many individuals with valuable skills and perspectives.

The calculus sequence taught in most engineering programs consists of an equivalent of three courses in calculus followed by a fourth in differential equations. The content of this four-

[15] Howson AG, Kahane L, Lauginie M, Tuckheim M (1988) Mathematics as a service subject. ICMI studies. Cambridge Books, Cambridge

course sequence has been accepted universally as the core mathematics content for all engineering majors. It poses three critical problems to be addressed:

1. A significant portion of the content of these courses is not actually needed by engineers who practice in the profession with a four-year degree.
2. Because of the overemphasis on calculus, there is not enough space for content in other essential areas of mathematics, such as statistics, data analytics, and modeling.
3. Math content is taught in a manner such that students fail to appreciate the connection of all the math they have to take with the engineering problems they need to solve. The stringent prerequisite structures, along with often punitive assessment practices, discourage many motivated and capable students who would have made excellent engineers.

The stringent pre-requisite structures, along with the punitive assessment practices that are commonly used, have effectively created an efficient filter and artificial barrier that “weeds out” many motivated and capable students from engineering programs who would have become excellent engineers.

The established mindset in engineering education is that calculus, in its current form and content, is absolutely essential in the formation of engineers. We need to move away from the use of mathematics (i.e., calculus) as a filter to keep students out of the profession. This, in turn, will make the profession significantly more inclusive by opening it up to a broader and more diverse population through the rejection of Calculus as a proxy for talent. Every motivated student will have a pathway to be successful in engineering. Faculty will be able to focus on student learning, success, and mastery of skills. The impact on engineering education will be significant.

Changing the perception and mindset of engineering from a major that is “only for those who are good in math and science” to one for everyone who wants to be a problem solver will transform engineering education from a “survival of the fittest” mentality to a growth or “gain the engineering skill” mindset. Every motivated student will have a path to success, increasing the number and diversity of students earning engineering degrees by removing math as an artificial barrier to the engineering career. The curriculum will better reflect professional engineering activity. Where applications of calculus/mathematics have been the curriculum's focus, there have been positive results on students’ perception of the relevance of mathematics for real-world solutions and their future study interests.

Removing calculus as a barrier to the engineering profession does not mean that mathematics is unimportant. Rather, the mindset is changed to view it as a one among many tools in solving engineering problems. The updated curriculum will better reflect professional engineering activity as students learn to become better problem solvers. *A design-by-choice flexible curriculum* will allow students to choose a program of study based on their interests, strengths, and career goals. This approach emphasizes student agency and autonomy as well as the importance of interdisciplinary learning and the acquisition of practical, real-world skills. Chapter 4 of this report has specific recommendations related to mathematics.

Moving Beyond the 1955 Grinter Report to Accommodate New Literacies

The Grinter Report ushered in important changes in engineering education, but since then curricular changes have been limited to tinkering around the edges (e.g., adding a capstone design project). A few topics have been added as they became relevant, and Fortran has been replaced with other programming languages along the way, but most of the changes involve adding and hardly ever subtracting. The basic structure of engineering education remains unchanged.

Today's students can instantaneously look up information on their smartphones that previously took hours to track down in the library or learn in the classroom. An internet search or AI can answer nearly any question (setting aside the question of accuracy or truthfulness). In short, the world has fundamentally changed, yet the curriculum and pedagogy have not kept up.

The New Literacies

The following new foundational literacy skills for engineers will build upon the traditional literacy skills of reading, writing, and mathematics[16]. They must be taught integratively and holistically, becoming foundational elements in engineering education.

- *Data literacy* includes reading, analyzing, and forming insight from data.
- *Technological literacy* includes coding, problem-solving, and using digital transformation tools, AI, the Internet of Things, and cloud computing.
- *Human literacy* involves better integration of humanities, communication, and design.
- *Higher-order mental skills* include an inclusive and growth engineering mindset and ways of thinking about the world.
- *Systems thinking* involves the ability to view an enterprise, machine, or subject holistically and connect different functions in an integrative way.
- *Entrepreneurship* applies the creative mind to the economic and social sphere.
- *Cultural agility* involves operating deftly in a varied and inclusive global environment.
- *Critical thinking* requires the habit of disciplined, rational analysis and judgment.

Artificial Intelligence (AI) in Engineering Education* (Shadow Box)

[16] Aoun, J. (2018). *Robot-proof: Higher Education in the age of Artificial Intelligence*. The MIT Press.

Historically, higher education has not been an early adopter of emerging technologies and, in many cases, has actively prevented using new technologies in teaching and learning. Early AI applications are already integrated into our everyday lives. With the recent release of ChatGPT to the public, the power of generative AI has become apparent. AI has the potential to revolutionize industries and everyday life by automating tasks, making processes more efficient, and enabling the development of new technologies. AI can reshape industries, enable new forms of communication and interaction, and unlock vast amounts of data-driven insights. AI has the potential to democratize access to information and knowledge by analyzing and interpreting vast amounts of data, making insights accessible to a broader audience.

While these potentials highlight different aspects of AI's significance as an emerging technology, they underscore its transformative potential across various domains of human activity. AI is poised to profoundly impact how we live, work, communicate, and interact with the world around us. However, it also comes with challenges that must be addressed to ensure its benefits are maximized while mitigating potential risks or unintended consequences.

Artificial Intelligence (AI) can revolutionize higher education in various ways, impacting students and educators. AI can potentially enhance the quality, efficiency, and accessibility of higher education by personalizing learning experiences, supporting educators, improving student success rates, and advancing research capabilities. AI can assist professors in teaching in several ways, improving efficiency, effectiveness, and student engagement. AI has the potential to augment professors' teaching abilities, improve student learning outcomes, and enhance the overall educational experience. By automating routine tasks, providing personalized support, and leveraging data-driven insights, AI can help professors focus their time and energy on what matters most: facilitating student learning and success.

However, addressing ethical and privacy considerations is essential to ensuring that AI technologies are deployed responsibly to maximize their benefits while mitigating potential risks. **Engineering programs should begin to create strategies and plans for AI's effective and ethical use to support and enhance student learning.** The strategies must include developing AI tools to support learning and identifying and encouraging students and faculty to use AI tools. This proactive response to AI will improve learning outcomes and allow faculty to dedicate more time to engaging with students.

**This section of the report was written with the assistance of AI.*

The US Economy Needs More Engineers

The Digital Age is rapidly accelerating global changes. Economies now and for the foreseeable future will be dominated by STEM industries that will drive technological advancement. Engineering is critical to resilience and solutions to problems associated with climate change, urbanization, the health of oceans and forests, and other global concerns, and an inclusive and gender-balanced profession is essential to realize the full human potential to solve these and other problems. Nations with a trained workforce involved in developing Industry 4.0 technologies, such as AI and quantum computing, will spur innovation-based competitiveness.

Engineering for Sustainable Development [17] reports widespread insufficient capacity and a need for more diversity. The future of America's defense will rely on advanced technologies such as AI, cyber, quantum, robotics, and hypersonics. But an insufficient and underprepared STEM workforce threatens national security. According to the 2021 US Defense Industrial Base (DIB) *Industrial Capabilities Report*, "The STEM shortage in the DIB is quickly approaching crisis status." The report calls for the United States to create a "state-of-the-art STEM education strategy to cope with this reality," warning that unless it "modernizes and adjusts," the country likely "will face a…permanent national security deficit."[18]

The Current System and Approaches are Not Working for Everyone

Despite decades of efforts to diversify and become more inclusive in engineering, we have seen incremental changes, made some progress, but we can do better. Despite all our efforts to improve graduation rates, our current higher education system and engineering education fall short in success rates for some groups. The three charts below show three disturbing trends for engineering education: of all the STEM disciplines listed in the table, 1) only physics and earth sciences have worse degree attainment than engineering, 2) the percentage of bachelor's degree attainment for African Americans in engineering has shown little improvement since 1995, and 3) although the raw number of women in engineering grew during a period of high growth in engineering undergraduates between 2010 and 2015, the percentage of women in engineering is growing at an excruciatingly slow pace despite a tailwind of more women attending college than men. Despite good intentions and efforts to improve these metrics, what we have been doing is NOT working.

When decades of effort do not improve outcomes, you must question the methodologies employed and fundamentally change the systems and processes employed to reach the desired outcomes.

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[17] Unesco.org. (2022). Available at: https://unesdoc.unesco.org/ark:/48223/pf0000375644.

[18] DOD OSD A&S Industrial Policy. *Fiscal Year 2020 Industrial Capabilities Report to Congress*. 2021. Pages 8, 104. https://media.defense.gov/2021/Jan/14/2002565311/-1/-1/0/FY20-INDUSTRIAL-CAPABILITIES-REPORT.PDF

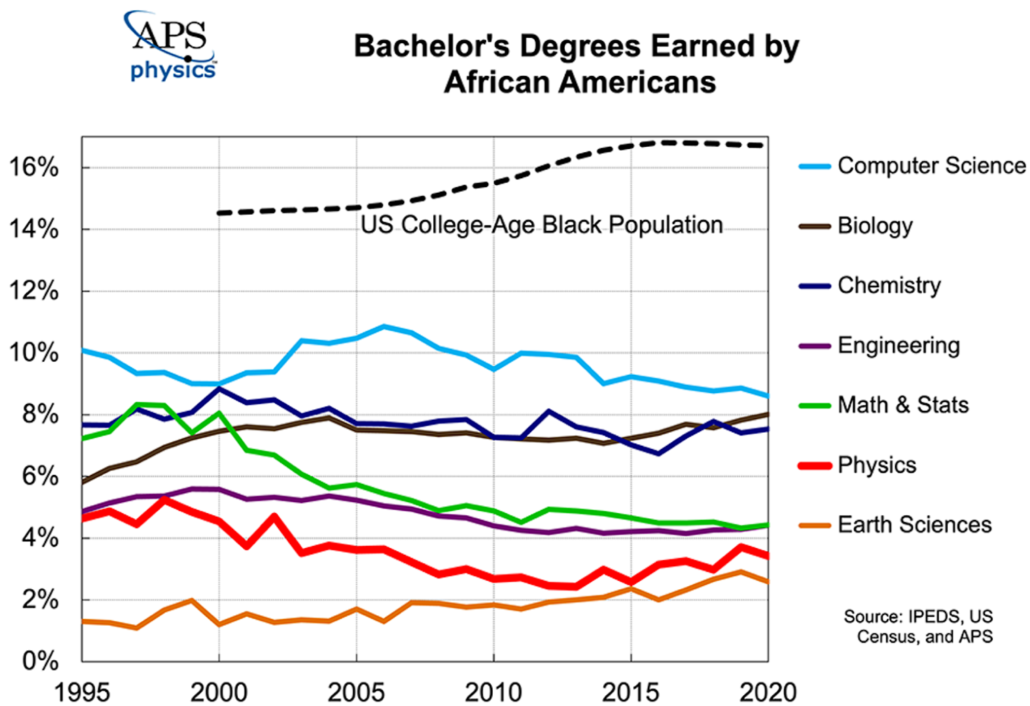

Figure 1 Bachelor's degrees Earned by African Americans in STEM disciplines.

Table 1 Percentage of Students Graduating by Ethnic Group in Engineering 2019

Percent

Field	White	Asian	Black or African American	Hispanic or Latino	American Indian or Alaska Native
Science	55.7	9.0	9.0	13.5	0.5
Engineering	59.3	10.8	3.9	10.4	0.3
Non-S&E	60.4	5.2	10.3	12.4	0.5

Source(s)

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations of U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System, Completions Survey, unrevised provisional release data. Related detailed data: WMPD table 5-3.

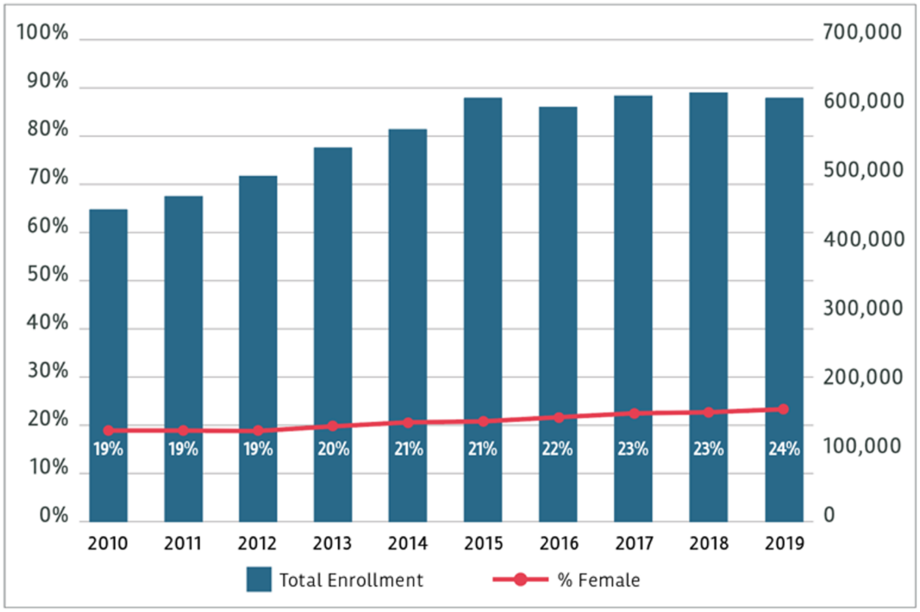

Figure 2 The percentage of women enrolled in engineering[19]

According to the US Bureau of Labor Statistics, in the past 30 years, US STEM employment has grown by 79%. But only 13% of engineers are women, only 19.4% of tenured/tenure-track faculty in engineering are women, and only 30% of women who earn bachelor's degrees in engineering are still working in engineering 20 years later.[20] [21] [22] Among those who have left the engineering profession, 30% cite organizational climate as the reason.[23]

According to Busch-Vishniac and Jarosz, for women and underrepresented groups, the engineering curriculum is downright unattractive, uninformative, and uninviting.[24]

For the engineering workforce to represent parity with the US population in 2030:

- The number of women in engineering would have to double.
- The number of African Americans in engineering would have to increase by 2.5 times.
- The number of Hispanics in engineering would have to triple.

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[19] Causey, J., Cohen, J., Lee, S., Ryu, M., & Shapiro, D., Current Term Enrollment Estimates Expanded Edition: Fall 2022, Herndon, VA: National Student Clearinghouse Research Center. February 2023.

[20] https://www.bls.gov/cps/cpsaat11.htm.

[21] https://swe.org/research/2023/tenure-tenure-track-faculty-levels/

[22] Corbett, C. & Hill, C. (2015). *Solving the equation: The variables for women's success in engineering and computing.* Washington, DC: American Association of University Women.

[23] Fouad, N. A., Singh, R., Fitzpatrick, M. E., & Liu, J. P. (2012). *Stemming the tide: Why women leave engineering.* University of Wisconsin, Milwaukee.

[24] Busch-Vishniac, Ilene & Jarosz, Jeffrey. (2004). Can Diversity in the Undergraduate Engineering Population BE Enhanced Through Curricular Change?. Journal of Women and Minorities in Science and Engineering. 10. 255. 10.1615/JWomenMinorScienEng.v10.i3.50.

Parity may not be the ultimate goal in engineering but we can do better. Despite ongoing efforts to attract more women, people of color, and other marginalized groups, much work still needs to be done to reach this country's full human potential in engineering as a profession.

Embedded Racial Bias in Our Society

Engineering is not strictly a technical discipline operating without human biases and sensibilities. It is essential to acknowledge, accept, and leverage the often implicit political power and privilege of engineering and engineers to counter racist societal norms. There is also a need to improve educators' and students' understanding of the historical events and structures that created or contributed to inequities and some of the problems that interfere with solutions. Educators and students need a solid understanding of the deeply held biases based on their experiences and their impacts on judgment and ability to solve problems equitably.

In STEM, 91% of university and college faculty are White (96% in more selective schools).[25,26] And although Black, Hispanic, and White students declare STEM majors at roughly the same rate,[27,28] 40% of Black students switch out of STEM majors before earning their degree.[29] The National Academies' 2023 consensus report *Advancing Antiracism, Diversity, Equity, and Inclusion in STEMM Organizations* states that people from minoritized racial and ethnic groups continue to face numerous systemic barriers that impede their ability to access, persist, and thrive in STEMM higher education and the workforce.[30]

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[25] Li, D., and Koedel, C. (2017). Representation and salary gaps by race-ethnicity and gender at selective public universities. Educational Researcher, 46, 343–354.

[26] Nelson, D.J., Brammer, C.N., and Rhoads, H. (2010). A national analysis of minorities in science and engineering faculties at research universities. Advance UC Davis. https:// ucd-advance.ucdavis.edu/post/national-analysis-minorities-science-and-engineering- faculties-reasearch-universities

[27] Xie, Y., Fang, M., and Shauman, K. (2015). STEM education. Annual Review of Sociology, 41, 331–357.

[28] Griffith, A.L. (2010). Persistence of women and minorities in STEM field majors: Is it the school that matters? Economics of Education Review, 29(6), 911–922.

[29] Riegle-Crumb, C., King, B., and Irizarry, Y. (2019). Does STEM stand out? Examining racial/ ethnic gaps in persistence across postsecondary fields. Educational Researcher, 48(3), 133–144. https://doi.org/10.3102/0013189x19831006

[30] National Academies of Sciences, Engineering, and Medicine; Division of Behavioral and Social Sciences and Education; Board on Behavioral, Cognitive, and Sensory Sciences; Committee on Advancing Antiracism, Diversity, Equity, and Inclusion in STEM Organizations. (2023). Advancing Antiracism, Diversity, Equity, and Inclusion in STEMM Organizations: Beyond Broadening Participation. In E. A. Vargas, L. A. Scherer, S. T. Fiske, & G. A. Barabino (Eds.), *PubMed*. National Academies Press (US). https://www.ncbi.nlm.nih.gov/books/NBK589214/

The backdrop to these statistics is a pervasive lack of acknowledgment of the racist US history that affects engineering education. This lack of acknowledgment precludes examination of the role of engineering administrators, faculty, staff, and students in the persistence of racism and inequity in the STEM culture. Unfortunately, diversity and access efforts are seen as a separate endeavor from the educational mission of STEM. This demarcation, compounded by the lack of acknowledgment, prevents members of the STEM community from thinking of diversity and access when designing engineering curricula. Connected and interrelated institutions (e.g., education and economics) will then inform what is taught and how. The pedagogical approach to STEM education will require educators to acknowledge the multiple identities of their students and create brave spaces for learners to explore how their social and cultural identities will impact the future of engineering.

The Consequences of the Status Quo

At the current pace of increasing access and diversity in US universities, it will take 300 years for college students to reflect the percentage of Native Americans and Blacks in the US population and more than 1,000 years to reach parity in faculty diversity for all universities. In other words, parity in our lifetimes will only be achieved with these groups only if something truly transformational is accomplished in engineering education.

The cost to the US economy and society by not serving all groups equitably is very high. Data show that the number of inventions in the United States would be four times higher if historically marginalized groups contributed at the same rate as men from high-income families. Further, all-women design teams are 35% more likely to focus on inventions for women's health.[31] Data show that "diverse teams are better at making decisions 87% of the time" versus teams that lack diversity.[32]

The nearly two-decade decline in the US birth rate means fewer high school graduates.[33] At the same time, there is an increase among college-going student populations that engineering struggles to attract and a decline in the populations that engineering typically attracts (NSF, The Missing Millions).[34]

Engineering degrees provide an opportunity to increase the economic and social mobility of families and communities that last for generations. Limiting who gets an engineering degree

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[31] Koning, R., Samila, S. and Ferguson, J.-P. (2021). Who do we invent for? Patents by women focus more on women's health, but few women get to invent. *Science*, 372(6548), pp.1345–1348. doi:https://doi.org/10.1126/science.aba6990.

[32] https://www.weforum.org/agenda/2023/01/davos23-gender-equality-stem-support-sustainable-economy/.

[33] Kearney, M., Levine, P. and Pardue, L. (2022). *The Mystery of the Declining U.S. Birth Rate | Econofact*. [online] econofact.org. Available at: https://econofact.org/the-mystery-of-the-declining-u-s-birth-rate.

[34] Clarke, D., Cutcher-Gershenfeld, J. and Michael, L. (2021). *The Missing Millions Democratizing Computation and Data to Bridge Digital Divides and Increase Access to Science for Underrepresented Communities*. [online] *PI*. Available at: https://www.rti.org/publication/missing-millions/fulltext.pdf.

negatively impacts lives and communities, safety, and our well-being as a nation. Increasing diversity in engineering will advance economic growth, development, and innovation and elevate the socioeconomic status of families and communities.

For much of its history, engineering has worked to weed out all but the perceived brightest and best under the assumption that most students did not have what it takes to be an engineer. While perceptions have broadened somewhat, and some overt practices designed to weed out students have been discontinued, many of the structures, policies, mindsets, traditions, and approaches still used in engineering education perpetuate the weed-out mentality.

Higher education and engineering education have a higher purpose in serving the nation and transforming the individual. Beginning in the late 19^{th} and early 20^{th} centuries, many higher education systems, including engineering education, became more institution-centric, making decisions and changes that favor the institution over the student. Theories such as an immutable intelligence quotient (IQ) and a behaviorist approach to teaching and learning at the expense of a more holistic approach created inflexible and unwelcoming learning environments that limit student potential. The sorting (exclusion) of students through admissions, grading, test scores, and other traditional measures must be replaced with a student-centric approach that ensures better student outcomes regardless of background.

Opportunity vs. Ability

Opportunity (or access) is incorrectly used as a proxy for ability and interest in engineering. Students with opportunity and better preparation through better K-12 schools and higher family incomes are more successful in being admitted and graduating with engineering degrees. In some cases, these are students of average ability. Conversely, students of similar ability are not admitted if they lack opportunity through no fault of their own.

Historically marginalized students are more likely to lack opportunity because of implicit biases, stereotypes, and other societal norms and structures that discourage and filter out opportunity pathways.

> Based on decades of research and analysis, racial disparities in STEMM careers do not rest on individual deficiency in candidates or even primarily on the individual racism of institutional and organizational gatekeepers. Racism is embedded in our society. For example, wealth disparities across generations contribute to and result from segregated neighborhoods; segregated neighborhoods contribute to unequal school quality, which deprives whole student cohorts of the opportunity to consider, prepare, and enter a career in STEMM. Further, racial wealth gaps affect families' ability to pay for STEMM college.[35]

[35]NASEM. 2023. *Advancing Antiracism, Diversity, Equity, and Inclusion in STEMM Organizations: Beyond Broadening Participation*, p. xix. https://doi.org/10.17226/26803

Educators, administrators, and institutions must change approaches to recruiting, admitting, educating, and graduating engineers to nurture interest and embrace the assets that students bring with them to college. Changes should include creating personalized pathways and on-ramps for students with engineering abilities to foster success and persistence instead of attrition.

The change advocated in the Report is NOT about lowering standards or the quality of our graduates. It is about setting appropriate expectations and helping students meet those expectations rather than expecting students to walk in the door already possessing the knowledge, skills, and background required to be successful.

Broadening access is critical to the future of engineering as a profession. Filtering for pre-college opportunities based on income and quality of the school attended is counterproductive. It is time to recognize the ability and interest of the nation's diverse array of students, welcome them into engineering, and provide support and thriving environments that empower them to become outstanding engineers. **The time has come for engineering education programs to become "student-ready" programs instead of serving only "college-ready" students.**

Advancing Engineering Education for the 21st Century

How many creative problem solvers who would have become excellent engineers have been driven from engineering programs or never given an opportunity over the years? How many inventors and entrepreneurs have been discouraged from developing and contributing their talent and ideas? How many out-of-the-box thinkers have left engineering because of the curriculum's rigidity and uninspiring nature?

The extent of the loss of human talent from engineering may never be known. But it must not continue. The recommendations in this report aim to offer steps to prevent further loss. Without the proposed much-needed changes, US engineering education perpetuates a great injustice and hinders our ability to solve humanity's most challenging problems.

As noted, the US undergraduate engineering education system is inflexible, uninspiring, unwelcoming, and unattractive to most of the population. It has not taken advantage of evolving knowledge about the science of learning since 1955 to improve teaching and learning and increase student success. With the high cost of university education, expanding opportunities (including online) for education at all levels, and changing demographics, failure to transform engineering education programs may make these programs outmoded and irrelevant.

To ensure that a diverse pool of capable and motivated learners is attracted to and retained in engineering programs, it is time to examine the type of problems students are asked to solve so that they are inspired to continue in engineering and contribute to the solutions that change the world for the better. This may mean omitting topics that are no longer relevant, especially those that can easily be looked up on our phones.

In this context, a Task Force, through a series of meetings and writing sessions, set out to review the current state of engineering education through an effort titled *The Engineering Mindset Report: A Vision for Change in Undergraduate Engineering & Engineering Technology Education*. This report is the culmination of that work.

CHAPTER 3. Create Flexible Program Structures to Remove Barriers

This section of the report will provide the background and recommendations to remove barriers into and within engineering and engineering technology. By removing key barriers, more students from diverse backgrounds will enter into engineering programs and find success. The key barriers addressed in this section include those in 1.) math and science, 2.) engineering fundamentals, 3.) inflexibility of the curricula, 4.) assessment, 5.) inflexibility of the pathways, and 6.) curricular inequities.

Math and Science

The traditional engineering curriculum at most colleges and universities requires a year or more of math and science courses as prerequisites to core sophomore-level engineering courses. In particular, the required math sequence for many engineering degree programs includes three semesters of traditional calculus as well as differential equations and matrix algebra (either combined or separately).

The average incoming engineering student at a typical comprehensive public university is substantially underprepared in math, with an initial math placement at only the college algebra level (two semesters behind the first calculus course). Moreover, the average American high school graduate is a full semester behind that, failing to meet college-ready benchmarks and consequently placing in developmental math.[36] Even high-achieving students were set back during Covid. The 2022 National Assessment for Educational Progress (NAEP) found that math scores for high-achieving students dropped as steeply as scores among low scorers.[37]

This makes the core engineering curriculum even more inaccessible to the vast majority of American high school graduates and transfer students without recent math coursework or nontraditional students returning to school from the workplace. This also has substantial implications for diversity and inclusion, as underrepresented minority students (who are more likely to come from underserved school districts) are disproportionately underprepared in math and science. While the required math sequence is arguably the primary curricular barrier to student success in engineering, the traditional science requirements in physics, chemistry, or biology also act as bottlenecks to many engineering degree programs. Collectively, these required math and science courses typically have among the highest DFW rates (students who get a grade of D or F or who withdraw), exacerbating the problem.

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[36] https://www.act.org/content/dam/act/unsecured/documents/2022/2022-National-ACT-Profile-Report.pdf

[37] *NAEP Mathematics: Mathematics Highlights 2022*. (n.d.). https://www.nationsreportcard.gov/highlights/mathematics/2022/

Here is a list of typical topics covered in the four math classes.

- **Calculus I:** Functions and Graph, Limits, and Continuity, The Derivative, Exponential, logarithmic, and inverse trigonometric functions, The derivative in graphing and applications, The Integral and the Fundamental Theorem of Calculus
- **Calculus II:** Analytic geometry, differentiation, and integration of exponential, logarithmic, and inverse trigonometric functions, differential equations, sequences and series, parametric equations, polar graphing.
- **Calculus III:** Three-Dimensional Space & Vectors Vector-Valued Functions, Partial Derivatives, Multiple Integrals, Vector Fields, Line Integrals, & Green's Theorem Surface Integrals, The Divergence & Stokes' Theorems
- **Differential Equations:** Analytic Geometry, Introduction & First Order Differential Equations. Numerical Methods, Systems of Two First Order Equations, Second Order Linear Equations, The Laplace Transform Fourier Series & Transforms

Many topics in the Calculus sequence can be deemed to be non-essential for students who will practice engineering with a 4-year degree. Further, in our current system, students complete all of their mathematics requirements in the first 1-2 years prior to when they are applied in their engineering courses. Many of the topics in the calculus sequence are not needed until or unless a student pursues a graduate degree in engineering, at which time the concept needs to be learned again (or sometimes for the first time). We need to assess the content of the calculus sequence critically and include only essential topics from this traditional calculus sequence to make room for other types of mathematical content in the curriculum. For example, in the current calculus sequence, students learn multiple methods for taking derivatives of complex functions under any set of circumstances. However, in our current era, taking derivatives of these complex functions can easily be accomplished through AI or even a simple internet search. Eliminating unnecessary topics from the calculus sequence will then make room for topics such as statistics/data analytics, the use of computational modeling tools to solve engineering problems, and critical assessment of results obtained through AI or internet searches. At the same time, instead of solely focusing on Calculus skills, we need to redefine engineering as the process of problem-solving and innovation using tools such as mathematics and the basic sciences (along with many other skills). In implementing a system such as this, it will be important to ensure that students have a certain degree of flexibility in making choices to complete the mathematics requirements for their engineering degree.

To shift engineering's focus to problem-solving, where math is used as a tool rather than a separate entity, relevant mathematical content should be introduced in the context of engineering problems and integrated with engineering topics where its application is essential. We need to de-emphasize "math just for the sake of math." Instead of assessing students directly on mastery of abstract math concepts, they could be assessed on their ability to apply these mathematical tools in engineering contexts.

The redesign of how math is taught should also include proven, student-centered best practices, including active learning, applications-based modeling, competency-based grading, and other similar instruction techniques. A focus on first principles and fundamental understanding should be the focus of the math content. Details can be looked up; fundamental understanding cannot.

The impact of these changes will be significant. With the refocusing of the math content, its delivery schedule, and the manner of delivery, it is expected that student perceptions of math will change from “math as an artificial barrier that needs to be overcome” to “a versatile tool whose use needs to be understood to solve societal problems.” The de-emphasis of Calculus in the curriculum as the sole requirement for mathematics learning will enable the inclusion of other critical math tools such as data analytics, statistics, machine learning, modeling tools, etc.

There is a need to revise engineering curricular structures to include more engineering context for math and science and remove curricular bottlenecks at the program level (e.g., the required calculus sequence). A substantial restructuring of the early engineering curriculum would be inherently transformative to engineering education, as most institutions' traditional curricular structure has been unchanged since the 1950s.

Over the past two decades, a number of institutions have sought alternative approaches to address the traditional math bottleneck. For example, Wright State University and dozens of its collaborating institutions have introduced new first-year engineering courses to provide incoming students with engineering context for math[38], which has been shown to increase student motivation and self-efficacy in both math and engineering.[39] When used as an alternative prerequisite path to core engineering courses, these courses allow for a more flexible and just-in-time delivery of the required calculus sequence.[40] This has contributed to substantial increases in engineering student persistence and degree attainment, with disproportionate benefits for underrepresented groups (including women and minorities).[41] Other institutions have created entirely new calculus sequences taught by engineering faculty, which inherently provides the required context for math in engineering. Still others have sought closer collaboration between math and engineering faculty in the teaching of calculus so that

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[38] Klingbeil, N.W., Mercer, R.E., Rattan, K.S., Raymer, M.L. and Reynolds, D.B., 2004, “Rethinking Engineering Mathematics Education: A Model for Increased Retention, Motivation and Success in Engineering,” Proceedings 2004 ASEE Annual Conference & Exposition.

[39] Klingbeil, N. and Bourne, T., 2014, “The Wright State Model for Engineering Mathematics Education: A Longitudinal Study of Student Perception Data,” Proceedings 2014 ASEE Annual Conference and Exposition.

[40] Finfrock, R. and Klingbeil, N., 2023, “Examining the Impacts of the Wright State Model for Engineering Mathematics Education through Curricular Analytics,” Proceedings 2023 ASEE Annual Conference and Exposition.

[41] Klingbeil, N. and Bourne, T., 2013, “A National Model for Engineering Mathematics Education: Longitudinal Impact at Wright State University,” Proceedings 2013 ASEE Annual Conference and Exposition, Atlanta, GA, June 2013.

mathematics educators are more aware of the contexts associated with the disciplines and students they serve.[42]

The impact of curricular restructuring on student success and degree attainment will vary by institution. At a comprehensive public university that traditionally graduates only a small fraction of its incoming engineering students, addressing the math bottleneck could substantially impact and improve engineering degree production. For example, results of a longitudinal study[34] showed that students who took Wright State's first-year engineering math course earned engineering degrees at more than *double* the rate of those who did not, with an even greater impact on women and minorities.

The impact on degree production would be less at selective private institutions that traditionally graduate a much larger percentage of their incoming engineering students. However, an engineering curriculum that is more accessible to students of all backgrounds (without sacrificing rigor) could allow private institutions to broaden their admissions policies, which could positively impact diversity and access.

In addition to the number and diversity of engineering graduates, this recommendation would likely have a measurable impact on time to degree, lowering the average cost of an engineering education. It would also provide a faster throughput of engineering graduates needed for high-demand jobs, which would have a positive economic impact on industrial constituencies and their broader communities.

New Engineering Fundamentals

The current set of engineering fundamentals and how they are delivered do not reflect the needs of society and the interconnectivity of the real world. Much of the core coursework early in the curriculum emphasizes theory, scientific concepts, calculus, and computer programming without relevant practical application.

To address this issue, we must redefine engineering fundamentals to better align with the socio-technical aspects and the skill sets that engineers use in practice. In addition, immersive and interactive learning strategies should be used to consciously develop a growth mindset to foster self-esteem, humility, and empathy among students. The redefinition of engineering fundamentals should focus on multidisciplinary connections across and beyond engineering, including ethics, policy, sustainability, liberal arts, and contemporary societal issues. These fundamentals will include a common set of multidisciplinary outcomes for the first two years of engineering (for all disciplines/eliminating disciplines) that can be achieved through multiple pathways. The vision is that a redefined set of fundamentals is broadly adopted and systemic change occurs in the engineering profession.

[42] Ganter, Susan and Haver, Bill (2022) "Interdisciplinary Collaboration to Develop Meaningful Mathematical Experiences," *Journal of Mathematics and Science: Collaborative Explorations*: Vol. 18: No. 1, Article 2.

A growth mindset supports student curiosity, self-awareness, flexibility, and lifelong learning. Allowing multiple pathways supports students in pursuing engineering regardless of prior preparation and better aligns with student interests and passions. Including opportunities early in the curriculum would allow student choice and explicit connections between abstract concepts and real-world applications.

Redefining engineering fundamentals to better align with society's needs and the skills that engineers use in practice can improve students' understanding of engineering and their comfort with ambiguity. Graduates will be more resilient engineers who can understand big-picture connections.

A multidisciplinary, life-centered, and practical approach to reimagining the engineering fundamentals will result in enhanced engineering student enrollment, engagement, and motivation to understand the complex nature of problems facing society.

Modularization

The current structure of the engineering curriculum restricts the pathways to the engineering profession to two: one aimed at those who pursue an engineering degree and the other aimed at those who pursue engineering technology degrees. Both curricula are rigid and inflexible, meaning students have few choices as they pursue their degrees. Prerequisite chains are long, adding rigidity to an already overconstrained system. Lack of choice and inflexibility are not attractive to today's students. Further, the curricular rigidity does not allow students to personalize their degrees, drawing on their unique strengths as they develop into professionals. The current structure does not accommodate different learning styles or starting points, meaning that some students automatically start "behind," simply decide not to start, or cannot catch up after struggling with an introductory course.

We have used the credit hour to subdivide learning into three credit hour silos defined by individual disciplines and individual faculty rather than by the knowledge needed to address complex problems. We have a very "efficient" system for learning consisting of a minimum of 1600 hours of class, 120 credit hours, and 40 classes, equaling one bachelor's degree. This is a relic of the factory model for education that is still with us today.

The advancement of learning sciences teaches us much about what knowledge is and how it is acquired. As individuals, we all learn at highly variable rates depending on the subject, our previous preparation, and life experiences. The Carnegie Foundation for the Advancement of Teaching, which developed the credit hour system, has launched an initiative to replace time (the credit hour) as the essential measure of learning.[43] Any efforts to transform learning in higher education must account for the ubiquity of the antiquated credit hour system and allow for other ways of delivering the curricula and measuring learning.

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[43] Sparks, S. D. (2022, December 8). The Head of the Carnegie Foundation Wants to Ditch the Carnegie Unit. Here's Why. *Education Week*.

Modularizing the curriculum will enable students to flexibly choose the fundamental and specialized modules they complete and will accommodate different starting points and interests.

With these changes, engineering education will be transformed in many ways. Modules can be scheduled flexibly throughout the semester so that students can better match their class schedule to the realities of their life outside of school (e.g., work or family obligations). Students will be able to learn at their own pace rather than the instructor's pace. Flexibility in module selection and scheduling will mean that students will have the opportunity to pursue subjects they are interested in, thus empowering them to personalize their degree. The result will be that students are more motivated and excited about what they are learning. They will feel an ownership of their degree. Modularizing content will deemphasize and uncouple prerequisite chains, enabling "just-in-time" learning.

In addition to the benefits accrued to students through this shift, faculty will also benefit. They will be empowered to be more nimble pedagogically (e.g., integrating project-based learning into technical learning). They will be able to teach the subjects they feel passionate about (for at least a portion of their overall teaching load) by developing modules on subjects such as the history of engineering, art in engineering, climate change and engineering, or some other topic that is currently ignored or unavailable. Less rigid teaching schedules will enable faculty to have greater autonomy to balance their teaching and scholarly activities better or take advantage of opportunities as short-term visiting scholars. Modularizing the curriculum will empower faculty to create schedules that afford them a better work/life balance.

Competency-based Assessment

One major issue with the current mindset of engineering education is that assessment structures attempt to *select* rather than *develop* talent, resulting in an artificial barrier to the engineering profession. Many faculty, and indeed the entire higher education system, have inherited an assessment structure that is used primarily because that's what has traditionally been used. Old assessment structures do not achieve an inclusive mindset for the future of engineering education. Pedagogy and curriculum built around traditional normative assessment structures are often competitive, designed to differentiate and select the most "talented" students, encourage students to learn as little as possible while playing the partial credit game and produce relatively meaningless course grades.

There is a need to create competency/mastery assessment structures for foundational coursework and throughout engineering education. A systemic change in engineering education must include a change in the way we assess student learning. Such structures have measurable and prioritized learning goals that students achieve at their own pace through personalized pathways and repeated opportunities for mastery demonstration.

These outcomes-based assessment structures are transformational because they seek to develop ALL interested students into engineering learners, promote an inclusive growth mindset, shift the ownership of learning to the student, allow students to have bad days, level the playing field despite individual backgrounds, set students up for success by building a stronger foundation for moving into the next learning goal, and indicate precisely what students have learned at the end of a module.

The shift in assessment structure is also transformational for faculty. Students know exactly what they must achieve and how it connects to the engineering profession and future coursework, increasing their engagement and interest. Thus, faculty become facilitators rather than judges, helping everyone achieve necessary foundational mastery, regardless of individual background and pace of learning. After long-term adoption, faculty time is more efficient through a reduction in making and grading assessments, as well as streamlining ABET reporting. Student test anxiety is lowered, and accommodations (e.g., for illness or other absences) are more easily managed. Faculty and students get out of the business of arguing partial points and stay focused on learning outcomes. Finally, faculty can safely assume students are prepared for their upper-level learning experiences because the emphasis has been on learning and mastering critical foundational skills.

Widespread adoption of competency/mastery assessment in engineering education would shift assessment away from selecting talent toward developing talent, as the assessment would demonstrate what students have and have not learned. Programs would use a student-centered approach rather than a curriculum-centered one, allowing for constant and critical evaluation of classroom learning and curriculum relative to students' needs. The student's primary goal becomes learning the material instead of achieving a particular grade, which will, in turn, increase engagement, motivation, confidence, self-awareness, interest—and perseverance to a degree.

Recommending competency-based assessment for engineering education is an inherent challenge when the higher education system continues to use and support traditional assessment techniques and practices. There is growing recognition that the credit hour and measuring learning by seat time are no longer useful.[27] Engineering education cannot make the recommended changes alone. Still, we can be leaders in developing competency-based education and assessment, leading to a higher education system that accommodates and embraces this advanced and more effective learning assessment.

Flexible Curricular Pathways

The engineering curriculum is among most institutions' least flexible undergraduate degree programs, creating barriers for many students. It is difficult to enter an engineering program at almost any point in life. First-time, full-time, direct-from-high-school students must have reasonable mathematics preparation. Transferring majors or institutions often extends the time to degree completion. Returning students may no longer be academically prepared, particularly mathematically, to enter most engineering programs. Students who cannot devote 4–6 continuous years of full-time study face significant barriers to degree completion.

Various career pathways are possible upon completing an undergraduate degree, including direct to industry, graduate school in engineering or other areas like law or medicine, entrepreneurship, or non-engineering careers like finance or teaching. We know that engineering graduates move on to non-engineering careers. The engineering curriculum does not match the reality of where graduates end up, and a rigid curriculum may prepare students well for only one or two of these options. This assumption harms society by reducing the number of people trained in engineering thinking and rigorous problem-solving, which is beneficial no matter where someone's pathway may lead.

Engineering education must develop multiple flexible pathways in undergraduate engineering programs—toward professional practice, graduate school, challenges not yet known—to prepare students for lifelong learning, provide more flexibility, allow more customization aligned with students' desired career goals, and broaden overall participation.

Engineering straddles the line between a professional program like law or medicine, where practice is an expected part of the program as students are prepared for specific careers, and a more traditional undergraduate program, where students receive a broader education that is not as career-focused. Allowing for more flexible pathways will yield more engineering graduates and more members of society with some engineering problem-solving experience. Engineers are often coveted in law, medicine, finance, industry, and other fields as they are trained to think systematically and solve problems within constraints. Increased numbers of engineering graduates, particularly nontraditional graduates and those with some level of engineering training, will ensure a better-equipped general population to solve the wicked problems of the future. Providing flexibility in course curricula that includes more options for electives, experiential learning, and sub-degree certifications will remove many barriers for nontraditional students in myriad ways.

- Engineering technology and engineering will be seen as viable, interconnected, and as a continuum of pathways to careers in engineering and other fields.
- Students will be able to make better choices about their career paths. Moving into engineering from engineering technology will be easier and readily available, particularly to historically marginalized and first-generation undergraduate students.
- Collaboration and communication between engineering technology and engineering students will be increased, which is better preparation for the future workplace.
- Integrating engineering technology and engineering courses will expose students to common foundational science and engineering principles and practical applications, which appeals to today's students and is more inclusive of women and minoritized students.
- Students will gain a broader range of skills and knowledge that will enable them to work proficiently on a wider variety of projects, better meeting the needs of future employers.

- Industry will have a much better-prepared workforce through the wide range of engineering skill sets that would result from the continuum of engineering technology and engineering BS degree graduates.

Identify and Address Curricular Inequities

Engineering curricula at the undergraduate level make strong assumptions about the students who enter our programs. Admission requirements, first-year program requirements, math requirements, and others are founded on narrow understandings of how students will present as engineering-ready and engineering-success-capable. The requirements and narrow understandings inherently favor certain groups (e.g., White males) and discourage or effectively exclude others.

Equity, as a concept, refers to situations where outcome achievement is independent of incoming states. Put another way, equity is a situation where outcomes can be equally achieved despite the starting situation. Equity has been hard to achieve in engineering programs, given the assumptions curricula make about students' necessary starting state. These inequitable assumptions revolve around one-size-fits-all math, typical grading and assessment practices, and linear sequences. And the consequences of these situations play out via the impacts of failed courses.

Engineering education must identify and address all inequities caused by the curricula (content, assessment, and pedagogy) and value diverse ways of thinking to prepare engineers. We must provide support, means, resources, and accountability for reducing inequities. All curricula must be evaluated and delivered with considerations of inequities as a prerequisite in its design and assessment based on competency. Specific recommendations can be found in Chapter 6 An Inclusive and Diverse Engineering Education Learning Environment

Recommendations: Flexible Program Structures to Remove Barriers

Recommendation 1.1. Instead of a one-size-fits-all all math requirement in the expected level of incoming math preparation, incorporate in-context mathematics across the introductory curriculum to help alleviate student inequities due to K-12, economic, first-generation, and other differences.

Many engineering programs start students in calculus taught in a very theoretical way. Our recommendation could lead to alternate paths toward engineering studies for students who come to university interested in engineering/engineering technology but need the adequate background to get started in their studies on the current curricula and typical paths to graduation.

While a good foundation in mathematics (including knowledge of linear algebra, geometry, trigonometry, matrices, vectors, calculus, and even statistics) is necessary for many engineering majors and their required major courses, mathematics out of context can be difficult for many students. Integrating realistic engineering problems in mathematics courses could help them develop fundamental understanding and lead to increased success. Similarly, teaching mathematics in an engineering context in math courses, assessing for competence, and explaining the need for math in engineering courses, how math-based concepts are needed across the curriculum (as with writing ability across the curriculum) for engineering/engineering technology students could help with mathematics success.

Recommendation 1.2: Modularize the engineering curriculum to allow students to flexibly choose their pathways through fundamental courses and as a means to offer electives on important and emerging topics in engineering and engineering technology.

The modules we envision will each be 0.25-1 credit (depending on the subject and/or institution) and will cover a wide variety of topics. Some modules could be required, but most should be elective. Modularization would allow new topics and foundational elements to be added to the curricula. The curricula would become much more flexible for the student and nimble for faculty when adding and removing topics. Important new literacies can be taught integratively and holistically and become foundational elements in engineering education if modularization is adopted in the curricula.

- *Data literacy* includes reading, analyzing, and forming insight from data.
- *Technological literacy* includes coding, problem-solving, and using digital transformation tools, AI, IoT, cloud computing, and quantum computing.
- *Human literacy* involves better integration of humanities, communication, and design.
- *Higher-order mental skills* include an inclusive and growth engineering mindset and ways of thinking about the world.
- *Systems thinking* involves the ability to view an enterprise, machine, or subject holistically and connect different functions in an integrative way.
- *Entrepreneurship* applies the creative mind to the economic and social sphere.
- *Cultural agility* involves operating deftly in a varied and inclusive global environment.
- *Critical thinking* requires the habit of disciplined, rational analysis and judgment.

Recommendation 1.3. Assess for competency (mastery) and employ formative assessments using techniques such as "ungrading" instead of focusing on current grading and assessment practices.

This approach not only addresses inequities in student experiences and support but can also offer alternatives to standard exam-based assessment. Some students may experience high levels of stress and anxiety that adversely affect their performance on exams, making the exam into an assessment, not of student understanding but instead of student stress.[44] [45] [46] [47]

Recommendation 1.4. Assess prerequisites to allow for maximum student flexibility and alternative pathways through the curricula.

Progress through curricula often has a linear sequence of courses and strict prerequisites, and while prerequisites are necessary because of the scaffolding of knowledge (e.g., understanding of certain mathematics principles to learn physics, math, and physics principles for success in dynamics). Reassessing which prerequisites are truly necessary to a given plan of study could help prevent students from getting multiple semesters behind in their studies by failing one course. Departments might even have plans for alternate paths, considering the courses that most often are failed by students the first time around. Modularization can also help with this recommendation. For example, the prerequisite for a given physics module could be only one relevant calculus module and not the entire calculus course.

Recommendation 1.5. Create student-centered paid internship and co-op programs integrated into engineering curricula that encourage, support, and recognize the value of work experiences.

Paid internships and co-ops should be encouraged because they positively impact student retention, graduation, and eventual employment, especially for minorities and women. Paid internships and co-ops are exceptionally impactful during student experiences but can be differentially available. Along with this recommendation is one to increase online course offerings so students on an internship or co-op can take courses part-time and remain on track to graduate in four or fewer years.

With equity-centered curricula and design as the foundation for undergraduate engineering and engineering technology, all students, particularly those from underrepresented backgrounds and experiences, will succeed and flourish in engineering programs. This is novel because we focus on changing the system that forms people rather than changing the people

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[44] Morphew, JW, Silva, M, Herman, G, West, M. Frequent mastery testing with second-chance exams leads to enhanced student learning in undergraduate engineering. Appl Cognit Psychol. 2020; 34: 168– 181. https://onlinelibrary.wiley.com/doi/abs/10.1002/acp.3605

[45] B. Chen, R. F. DeMara, S. Salehi and R. Hartshorne, "Elevating Learner Achievement Using Formative Electronic Lab Assessments in the Engineering Laboratory: A Viable Alternative to Weekly Lab Reports," in IEEE Transactions on Education, vol. 61, no. 1, pp. 1-10, Feb. 2018, doi: 10.1109/TE.2017.2706667

[46] Linke, M., Landenfeld, K. Competence-based learning in engineering mechanics in an adaptive online learning environment, Teaching Mathematics and its Applications: An International Journal of the IMA, Volume 38, Issue 3, September 2019, Pages 146–153. https://academic.oup.com/teamat/article-abstract/38/3/146/5553679?redirectedFrom=fulltext&login=false

[47] Hafeez, M.A., Shakil, S., & Jangsher, S. (2018). Stress Effects on Exam Performance using EEG. 2018 14th International Conference on Emerging Technologies (ICET), 1-4.
https://ieeexplore.ieee.org/document/8603652

who populate the system.

Recommendation 1.6: Create curricula and support structures that provide more seamless transitions between engineering technology and engineering undergraduate degree programs while ensuring students are prepared with the necessary skills and knowledge to succeed in their chosen field.

When looking at multiple pathways into engineering, the Task Force considered the contributions of BS engineering technology programs in preparing engineers. Efforts to legitimize engineering technology as a pathway into engineering professions should be considered. This approach will lessen the divide between engineering technology and engineering programs, as advised in the 1955 Grinter Report. ("elimination… (of) those courses of a high vocational or skill content and those primarily attempting to covey engineering art and practice"). Lessen the social inequities in education that often funnel historically minoritized and marginalized racial and ethnic groups (historically minoritized and marginalized racial and ethnic groups) students into engineering technology. High school students interested in engineering but have not had the opportunity to take higher-level mathematics are often advised to pursue engineering technology. Engineering technology has a much higher proportion of historically minoritized and marginalized racial and ethnic groups male students than engineering, but this demographic also reflects existing educational inequities. If both engineering technology and engineering graduates were recognized as engineers, this goes away as a "problem." The K-12 inequities still exist, but this cost does not need to continue. Ease the transfer issues between engineering technology and engineering programs. Transfers between engineering technology and engineering programs are difficult, and students often do not receive transfer credit for completed engineering technology courses. Create curriculum and support structures that provide more seamless transitions both ways between engineering technology and engineering undergraduate programs while ensuring students are prepared with the necessary skills and knowledge to succeed in their chosen field.

CHAPTER 4. Evidence-based Pedagogy: Creating a Student-Centered Engineering Education

While many systemic recommendations have emerged that focus on providing "flexible structures," changes need to be initiated in the classroom and the laboratory (and even assigned work outside of formal educational spaces), where faculty immediately impact student learning. Research provides compelling evidence on the effectiveness of teaching practices such as "cooperative learning; problem-based learning; peer-led team learning; process-oriented, guided inquiry learning; and project-based learning over lecture-based teaching to increase student learning, engagement, and success in STEM fields".[48] This may be because faculty are not aware of the teaching practices, or because adoption is hampered by barriers such as limited time, departmental norms, and physical classroom constraints, among others. Adoption of improved teaching practices may be enabled by administrative support, collaboration with colleagues, use of educational technology, and, more importantly, noticing improvements in student learning.

Barriers to implementing the recommendations in this section can be institutional, practical, and technological. Institutional challenges include the misalignment of faculty roles and institutional reward structures, a lack of clear metrics for teaching performance, an overcrowded curriculum, and resistance from those who benefit from the status quo. In addition to institutional barriers, faculty may experience practical challenges such as lack of familiarity or skills for implementing the teaching practices or new technologies, fear of student resistance and teaching evaluations, lack of time and resources (including adequate teaching spaces), and staff and expert support. Adopting new technologies for teaching practice may also be challenging. While technology can be instrumental in helping academia scale learning, it can also limit innovation. For instance, systems designed around traditional teaching user flows often inhibit the exploration of new teaching, learning, evaluation, and assessment methods. The challenge is evident, for example, in grading practices that deviate from the traditional approach of one grade per assignment. Future technology platforms need to be built for alternative approaches to learning and evaluation. Without technological support, many new approaches simply cannot be developed or integrated into existing operations.

To fully integrate educational technology in support of engineering education, faculty may have to rethink what they teach, how they teach it, and through what media. This does not mean that everything needs to be redesigned, but it does mean that some things will have to change. For this they will need time, resources, support, training and professional development, and

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[48] Finelli, C. J., & Froyd, J. E. (2019). Improving Student Learning in Undergraduate Engineering Education by Improving Teaching and Assessment. *Advances in Engineering Education, 7*(2), 1-30. p. 17.

ongoing classroom support from experts on teaching, learning, and discipline-based education. Educational technologies that respond flexibly and pedagogically to both faculty and learners' needs must be created and adopted. Educational technologies present an opportunity to support teaching practice by providing virtual collaborative spaces (e.g., Zoom, MS Teams), enabling scaffolding (e.g., problem-based learning platforms, computational notebooks for programming), and supporting feedback (e.g., intelligent tutoring, automatic grading, personalized feedback). Furthermore, recent advances in AI, such as ChatGPT and similar large language-based AI systems, have shown great potential for interpreting complex input and generating similarly complex output. It seems reasonable to think that these systems could be used in the near future to deliver individualized learning experiences to students, along with closely coupled evaluation and relevant feedback to help them improve.

This section of the report suggests implementing evidence-based and inclusive instructional practices that integrate active and hands-on learning, supported by educational technology, and contextualize learning in authentic experiences that increase student participation to better engage them early with an engineering mindset and create students' engineering identity. By prioritizing student experiences and having faculty adopt an inclusive coaching mindset, the learning experience for all students will positively impact their professional development.

Recommendations: Evidence-based Pedagogy: Creating a Student-Centered Engineering Education

In addition to Chapter 4 of the report offering guidelines on the *design* of learning experiences (through projects and activities that closely resemble the professional engineering context and tasks), it is equally important to consider evidence-based strategies on how to *orchestrate and deliver* those learning experiences. The desired outcome of these recommendations is for faculty to transition from teacher-centered approaches to learner-centered approaches or human-centered approaches where students:

(a) engage actively, constructively, and interactively as opposed to passively[49] and

(b) have meaningful opportunities to integrate their knowledge and disciplinary practices in the context of real-world projects,[50] [51] and

[49] Chi, M.T., and Wylie, R. 2014. The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist* 49(4):219–43.

[50] Fougt, S.S., Misfeldt, M., and Shaffer, D.W. 2019. Realistic authenticity. *Journal of Interactive Learning Research* 30(4):477–504.

[51] Shaffer, D.W., and Resnick, M. 1999. "Thick" authenticity: New media and authentic learning. *Journal of Interactive Learning Research* 10(2):195–216.

(c) have multiple and fair opportunities to demonstrate their knowledge.[52] [53]

For this, faculty need to adopt research-based teaching practices and, at the same time, explore the effectiveness of such changes on student learning through scholarly approaches. Below are some specific strategies for how programs may change their overall approach to engineering education to accomplish these goals.

Recommendation 2.1: Integrate hands-on and collaborative learning pedagogies that balance student ownership and choice and effectively working with others.

To attract and retain a wider range of students, faculty must embrace flexible and inclusive teaching approaches that recognize students' unique gifts and interests, for example with just-in-time, hands-on, and project-based learning that allows for student choice and ownership and is more reflective of engineering practice.

Principles of inclusive pedagogy can be used to make the content more meaningful for students by emphasizing their cultural and life experiences and ways to facilitate the learning processes as they work individually and with others.[54] Also, guidance from universal design for learning can engage learners purposefully by providing them with resources, skills, and strategies that keep them motivated and goal directed.[55] Together, principles of inclusive pedagogy and guidance from universal design for learning advocate for **teaching practices that ensure that all learners, including those who may be excluded or marginalized by the process of schooling,[56] can access and participate in meaningful and challenging learning opportunities[57]**. Principles of inclusive pedagogy include:

- *coagency*, where the responsibility of learning is shared between instructors and learners;
- *trust* between instructors and learners regarding shared responsibility in the learning process; and
- *inclusion*, to enhance learning for all through participation in a community and shared experiences.[58]

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[52] Nieminen, J.H. 2022. Assessment for Inclusion: Rethinking inclusive assessment in higher education. *Teaching in Higher Education*, DOI:10.1080/13562517.2021.2021395.

[53] Tai, J., Ajjawi, R., and Umarova, A. 2021. How do students experience inclusive assessment? A critical review of contemporary literature. *International Journal of Inclusive Education*, 1-18.

[54] Addy, T.M., Dube, D., Mitchell, K.A., and SoRelle, M. 2021. *What Inclusive Instructors Do: Principles and Practices for Excellence in College Teaching*. Stylus Publishing, LLC.

[55] Dewi, S.S., and Dalimunthe, H.A. 2019. The Effectiveness of Universal Design for Learning. *Journal of Social Science Studies* 6(1):112–23.

[56] Spratt, J., and Florian, L. 2015. Inclusive pedagogy: From learning to action. Supporting each individual in the context of "everybody." *Teaching and Teacher Education* 49:89–96.

[57] Hitchcock, C., Meyer, A., Rose, D., and Jackson, R. 2002. Providing new access to the general curriculum: Universal design for learning. *Teaching Exceptional Children* 35(2):8–17.

[58] Florian, L., and Linklater, H. 2010. Preparing teachers for inclusive education: Using inclusive pedagogy to enhance teaching and learning for all. *Cambridge Journal of Education* 40(4):369–86.

Principles of universal design for learning include

- the design of *engaging* experiences that are purposeful so students stay interested and motivated;
- presentation of information and content in *different formats,* supporting students in acquiring, processing, and integrating information; and
- opportunities for learners to differentiate the way they can *express what they know*, so they become strategic and goal-directed.[38]

While inclusive pedagogy and universal design principles do not provide specific guidelines on how to implement or orchestrate learning in and outside of classrooms, there are evidence-based teaching practices that align with these principles. For instance, problem-, project-, and inquiry-based learning approaches involve hands-on experiences where learners investigate complex issues or situations and identify solutions to problems through collaboration.[59] Such practices could encompass the principles of *coagency* and *engagement* by providing students with a level of responsibility for their learning process as they engage in solving real-world, meaningful problems. These strategies can be further enhanced with principles of cooperative learning to further promote *trust* and *inclusion* among team members. For example, the principle of *positive interdependence* can establish that the individuals in a group contribute to the project's success via common goals; the principle of *promotive interaction* can encourage team members to contribute and share resources; and the principle of *individual accountability* can ensure each team member contributes to their fair share of the group's work.[60] Such evidence-based strategies provide steps and guidance that assist faculty in sequencing the learning process, resulting in the construction of knowledge through active and collaborative student work in groups.[42]

Recommendation 2.2: Implement methods to support learners both in and outside the classroom (e.g. through scaffolding, etc).

Support and direction are necessary to guide students through the learning process. Such assistance increases their success, confidence, motivation, and perseverance. While teaching practices that focus on project-based or collaborative learning (among others) facilitate classroom orchestration, it is also important to **support learners as they engage in team-based projects and individual assignments outside of the classroom**.

Relevant to this support is the notion of *scaffolding*. Scaffolding refers to supports embedded in learning activities so that students take advantage of the tasks they can complete and receive relevant guidance for activities or tasks they cannot complete.[61] Carefully designed

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59 Acton, R. 2019. Mapping the evaluation of problem-oriented pedagogies in higher education: A systematic literature review. *Education Sciences* 9(4):269.

60 Johnson, D.W., Johnson, R.T., and Smith, K.A. 2014. Cooperative learning: Improving university instruction by basing practice on validated theory. *Journal on Excellence in University Teaching* 25(4):1–26.

61 Vygotsky, L.S., and Cole, M. 1978. *Mind in Society: Development of Higher Psychological Processes*. Harvard University Press.

instructional scaffolds can help keep learners engaged by presenting challenges to them and help them acquire integrated knowledge and skills. For example, cognitive apprenticeship proposes six scaffolding methods to help students acquire integrated knowledge and skills: (1) modeling, where the instructor demonstrates how to perform a task; (2) coaching, with the instructor's observation and facilitation at the moment students perform a task; (3) scaffolding, support methods to help students perform a task; (4) articulation, in which instructors encourage students to state their knowledge and thinking; (5) reflection, where instructors enable students to compare their performance with experts; and (6) exploration, prompting students to solve problems on their own.[62]

The timing of the support is also relevant. While cognitive apprenticeship methods advocate for direct instruction and scaffolding throughout the learning process,[63] other approaches, such as productive failure or inventing with contrasting cases,[64] may call for guiding students to invent solutions before receiving formal instruction. The latter approaches are designed to steer students in noticing key features of domain knowledge, thereby developing productive prior knowledge that a subsequent lesson can capitalize on to promote transfer.[65] [66] [67]

While cognitive apprenticeships and productive failure approaches are often used in the context of classroom instruction for guidance, **scaffolding is also needed outside of the classroom**. In this regard, instructors could benefit from technology integration. Technology-enhanced learning environments can enable forms of scaffolding throughout the design, problem-solving, or inquiry cycles.[68] [69] Such scaffolding can support (a) process management through specific inquiry or design stages; (b) meaning-making processes such as identification and engagement, exploration, and reconstruction; (c) articulation processes such as presentation and communication; and (d) reflection and negotiation processes.[51]

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[62] Collins, A., and Kapur, M. 2014. Cognitive apprenticeship. In *The Cambridge Handbook of the Learning Sciences*, ed. R.K. Sawyer. Cambridge, UK: Cambridge University Press.

[63] Collins, A., Brown, J.S., and Newman, S.E. 1989. Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser* 18:32–42.

[64] Schwartz, D.L., Chase, C.C., Oppezzo, M.A., and Chin, D.B. 2011. Practicing versus inventing with contrasting cases: The effects of telling first on learning and transfer. *Journal of Educational Psychology* 103(4):759.

[65] Loibl, K., Roll, I., and Rummel, N. 2017. Towards a theory of when and how problem solving followed by instruction supports learning. *Educational Psychology Review* 29(4):693–715.

[66] Schwartz, D.L., and Bransford, J.D. 1998. A time for telling. *Cognition and Instruction* 16(4):475–522.

[67] Schwartz, D.L., and Martin, T. 2004. Inventing to prepare for future learning: The hidden efficiency of encouraging original student production in statistics instruction. *Cognition and Instruction* 22(2):129–84. doi:10.1207/s1532690xci2202_1

[68] Kim, M.C., and Hannafin, M.J. 2011. Scaffolding problem solving in technology-enhanced learning environments (TELEs): Bridging research and theory with practice. *Computers and Education* 56(2):403–17.

[69] Quintana, C., Reiser, B.J., Davis, E.A., Krajcik, J., Fretz, E., Duncan, R.G., Kyza, E., Edelson, D., and Soloway, E. 2004. A Scaffolding Design Framework for Software to Support Science Inquiry. *Journal of the Learning Sciences* 13(3):337–86.

For instance, in the context of data science, programming, or computational engineering courses, instructors could use computational documents[70] as a technology-enhanced learning environment. Computational documents are web-based solutions allowing the authoring and execution of code in a single document.[71] Practitioners have used computational documents (e.g., Google Collabs, Jupyter Notebooks) to share work and collaborate, and they can also be used for education as they make possible the delivery of programming content more accessible for teaching and learning by supporting visualization of code execution and other forms of multimedia (e.g., text, images, and videos). Sense-making scaffolding can be provided in the form of programming worked-out examples.[72] Articulation scaffolding can be elicited in the form of explanation and argumentation prompts where students explain either their code or the outputs of the code (e.g., graphs and charts).[73] Process management can guide students to enact the entire data science, problem-solving], or the modeling and simulation cycles.[74] Finally, reflection scaffolding can support retrospective review, reflection on, and evaluation of results, including elements of collaboration.[75]

Recommendation 2.3: Align time and evaluation with expected outcomes via inclusive assessment practices and continuous formative feedback.

Assessment is central to higher education. Thus, educational researchers have emphasized the critical role of aligning learning outcomes with evidence of learning in the form of assessments.[76] However, we recommend that faculty take a step beyond that alignment by also integrating inclusive assessment practices. Assessment is central to higher education. Thus, educational researchers have emphasized the critical role of aligning learning outcomes with evidence of learning in the form of assessments.[59] We recommend that faculty take a step beyond that alignment by also integrating *inclusive assessment practices*.

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[70] Granger, B., and Pérez, F. 2021. Jupyter: Thinking and Storytelling with Code and Data. *Computing in Science and Engineering* 23(2):7–14.

[71] Wang, A.Y., Mittal, A., Brooks, C., and Oney, S. 2019. How data scientists use computational notebooks for real-time collaboration. *Proceedings of the ACM on Human-Computer Interaction* 3(CSCW):1–30.

[72] Vieira, C., Yan, J., and Magana, A.J. 2015. Exploring design characteristics of worked examples to support programming and algorithm design. *Journal of Computational Science Education* 6(1):2–15.

[73] Vieira, C., Magana, A.J., Roy, A., and Falk, L.M. 2019. Student explanations in the context of computational science and engineering education. *Cognition and Instruction* 32(7):201–31. doi:10.1080/07370008.2018.1539738

[74] Sánchez-Peña, M., Vieira, C., and Magana, A.J. 2022. Data science knowledge integration: Affordances of a computational cognitive apprenticeship on student conceptual understanding. *Computer Applications in Engineering Education* 31(2):239–59. http://doi.org/10.1002/cae.22580

[75] Jaiswal, A., Lyon, J.A., Zhang, Y., and Magana, A.J. 2021. Supporting student reflective practices through modelling-based learning assignments. *European Journal of Engineering Education* 46(6):987–1006. https://doi.org/10.1080/03043797.2021.1952164

[76] Wiggins, G.P., and McTighe, J. 2005. *Understanding by Design*. Alexandria, VA: Association for Supervision and Curriculum Development.

Traditional forms of assessments in engineering practice are largely based on exams, which tend to result in discrepancies in achievement between racial and ethnic groups.[77] In contrast, inclusive assessments focus more on laboratory or project-based assessments, where differences are not as pronounced.[60] Principles of universal design can also inform inclusive assessment practices by, for example, providing students with a choice on how to demonstrate their knowledge or engaging them in codesigning assessments and policies. [35] [36] Similarly, *fair assessment practices* give students equitable opportunities to demonstrate learning.[78] These practices consider the timing and variation of the assessment methods, such as (a) assessing often to give students multiple opportunities to demonstrate what they know, (b) assessing both process and product, and (c) assessing individual as well as collaborative work. [61] The logistical implications of inclusive assessment are vast, as they involve substantial time and resources. This type of assessment may also involve the training of teaching assistants and undergraduate graders who often perform the assessment of the learning.

Feedback is related to assessment: assessment is a summative mechanism for accountability, and feedback is a formative mechanism for learning. Timely feedback involves communicating with students to modify or guide their thinking or behavior to improve their learning.[79] It is presented as a response to some action performed by the learner or product created by the learner. The feedback can take the form of verification indicating the level of accuracy, explanation elaborating on the correct answer, a hint to guide the learner on the path toward a correct solution, and a worked-out example with details or procedures for approaching a sample solution.[62]

Feedback should be timely and personalized. The traditional large-size enrollments in engineering classrooms pose challenges to inclusive assessment practices, and providing timely and effective feedback can be even more challenging. Two strategies can support the delivery of feedback: peer feedback and automatic feedback. Peer feedback involves students providing feedback on their work or performance to one another and has been mainly applied in the context of higher-order thinking or professional skills, such as in the context of problem-based and team-based learning.[80] According to research findings, peer feedback, especially in the context of collaborative learning, can lead to positive outcomes.[63] It is valuable for the learner receiving the feedback and those offering it, as the process can improve students' metacognitive and reflection skills.[81] However, implementing peer feedback may also require

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[77] Traxler, A., Henderson, R., Stewart, J., Stewart, G., Papak, A., and Lindell, R. 2018. Gender fairness within the force concept inventory. *Physical Review Physics Education Research* 14(1):010103.

[78] Suskie, L. 2000. Fair assessment practices: Giving students equitable opportunities to demonstrate learning. *AAHE Bulletin* 52(9):7–9.

[79] Shute, V.J. 2011. Stealth assessment in computer-based games to support learning. *Computer Games and Instruction* 55(2):503–24.

[80] Lerchenfeldt, S., Mi, M., and Eng, M. 2019. The utilization of peer feedback during collaborative learning in undergraduate medical education: A systematic review. *BMC Medical Education* 19(1):1–10.

[81] Ballantyne, R., Hughes, K., and Mylonas, A. 2002. Developing procedures for implementing peer assessment in large classes using an action research process. *Assessment and Evaluation in Higher Education* 27(5):427–41.

other considerations, such as training learners on providing effective feedback to avoid negative outcomes such as scoring bias, peer leniency, and student discomfort.

Feedback practices can also be supported by technology when those can be automated. Automatic feedback can benefit learners by increasing student performance in activities,[82] particularly those that are structured and procedural (e.g., programming assignments). With advances in artificial intelligence (AI), such as genetic algorithms and deep learning, technology will be better positioned to support instructors with affordances such as prediction of learning performance, personalized resource recommendations to learners, and automatic assessment of higher-order thinking skills.[83] However, those advances need to be guided and grounded in learning theory and validated by empirical education research before being widely adopted in the classrooms.[66]

Recommendation 2.4: Engage and support faculty in some form of systematic professional development and evaluation of their educational innovations through scholarly approaches.

Despite extensive evidence of the effectiveness of research-based teaching practices, these have not been widely adopted by engineering faculty.[84] Although research has shown that faculty professional development is a viable mechanism to support adoption of evidence-based practices,[85] [86] raising awareness or increasing faculty knowledge about pedagogical methods, learning theories, or principles of good instruction may not result in faculty adopting research-based teaching practices.[87] That is, while faculty may change their beliefs and intentions after participating in professional development, their practice may not become more student-centered as a result.[88] Thus, **faculty development programs also need to be informed by research on strategies that promote instructors' adoption of research-based practices to improve student learning.[67]** What has been identified as a predictor of shifts in pedagogical beliefs from instructor- to student-centered approaches is faculty identifying changes in their

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82 cavalcanti, A.P., Barbosa, A., Carvalho, R., Freitas, F., Tsai, Y.-S., Gašević, D., and Mello, R.F. 2021. Automatic feedback in online learning environments: A systematic literature review. *Computers and Education: Artificial Intelligence* 2:100027.

83 Ouyang, F., Zheng, L., and Jiao, P. 2022. Artificial intelligence in online higher education: A systematic review of empirical research from 2011 to 2020. *Education and Information Technologies* 27(6):7893–925.

84 Finelli, C.J., and Froyd, J.E. 2019. Improving Student Learning in Undergraduate Engineering Education by Improving Teaching and Assessment. *Advances in Engineering Education* 7(2):1–30.

85 Faseyitan, S., Libii, J.N., and Hirschbuhl, J. 1996. An in service model for enhancing faculty computer self-efficacy. *British Journal of Educational Technology* 27(3):214–26.

86 Finelli, C.J., Daly, S.R., and Richardson, K.M. 2014. Bridging the research-to-practice gap: Designing an institutional change plan using local evidence. *Journal of Engineering Education* 103(2):331–61.

87 Lin, C.C., Yu, W.W., Wang, J., and Ho, M.-H. 2015. Faculty's Perceived Integration of Emerging Technologies and Pedagogical Knowledge in the Instructional Setting. *Procedia-Social and Behavioral Sciences* 176:854–60.

88 Rienties, B., Brouwer, N., and Lygo-Baker, S. 2013. The effects of online professional development on higher education teachers' beliefs and intentions towards learning facilitation and technology. *Teaching and Teacher Education* 29:122–31.

students' learning.[89] Thus, faculty professional development programs must be contextualized in their discipline and also integrate methods and support to systematically evaluate the integration of research-based teaching practices through the scholarship of teaching and learning, action or classroom-based research, or design-based research. Supports in this process may include access to experts in discipline-based education research, educational technologists, librarians,[90] connections with faculty with similar goals, institutional and administrative support in implementing their innovations in their classrooms, participating in action research, and disseminating results.[91]

Principles of *transformative learning* can inform the design and implementation of faculty professional development programs contextualized in their teaching practice and discipline. Transformative learning informs adult education, where adults learn as they adapt to the needs and demands of their sociocultural context.[92] [93] As adults engage in their communities, they seek to acquire new skills to perform different roles or new ways of performing current roles. That is, goals represent desires to adapt more effectively to demands they perceive in their contexts. The ultimate goal of transformative learning is that individuals change in a frame of reference,[94] a change that occurs as they acquire a coherent body of experience. For this process to occur, it is important that individuals engage in experiences by actively learning and engaging as they move from one activity to another. **Individuals *actively learn* in workshops and professional development programs, and they *actively engage* in the classroom, experimenting with new teaching approaches and identifying the outcomes**. Faculty must be supported as they engage in both types of activities by experts or by creating communities as learning environments[95] and engaging instructors in critically reflecting on their experience.[96]

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[89] Levin, T., and Wadmany, R. 2005. Changes in educational beliefs and classroom practices of teachers and students in rich technology-based classrooms. *Technology, Pedagogy and Education* 14(3):281–307.

[90] Levesque-Bristol, C., Flierl, M., Zywicki, C., Parker, L. C., Connor, C., Guberman, D., Nelson, D., Maybee, C., Bonem, E., FitzSimmons, J., and Lott, E. 2019. *Creating Student-Centered Learning Environments and Changing Teaching Culture: Purdue University's IMPACT Program.* Champaign, IL: National Institute for Learning Outcomes Assessment.

[91] Sunal, D.W., Hodges, J., Sunal, C.S., Whitaker, K.W., Freeman, L.M., Edwards, L., Johnston R.A., and Odell, M. 2001. Teaching science in higher education: Faculty professional development and barriers to change. *School Science and Mathematics* 101(5):246–57.

[92] Kitchenham, A. 2008. The evolution of John Mezirow's transformative learning theory. *Journal of Transformative Education* 6(2):104–23.

[93] Mezirow, J. 2018. Transformative learning theory. In *Contemporary Theories of Learning,* 2nd ed. London: Routledge.

[94] Mezirow, J. 1997. Transformative learning: Theory to practice. *New Directions for Adult and Continuing Education* 1997(74):5–12.

[95] Southern, N.L. 2007. Mentoring for transformative learning: The importance of relationships in creating learning communities of care. *Journal of Transformative Education* 5(4):329–38.

[96] Christie, M., Carey, M., Robertson, A., and Grainger, P. 2015. Putting transformative learning theory into practice. *Australian Journal of Adult Learning* 55(1):9–30.

The implications of grounding professional development in principles of transformative learning also suggest that design-based research approaches, action research, and other forms of scholarship of teaching and learning must become integral components of faculty professional development; therefore, faculty must be supported and guided in this process. As faculty engage in scholarly activities, they can (a) solve immediate educational problems by addressing students' specific learning needs or challenges with evidence-based teaching practices, (b) contribute to and disseminate new knowledge and practice for teaching and learning in their disciplines, and (c) notice the impact of the integration of evidence-based practices and adopt them permanently in their teaching.

Recommendation 2.5: Identify or create digital technology platforms to support alternative approaches to learning and evaluation.

Digital transformation is a driving force spurred by the confluence of four profoundly disruptive technologies: elastic cloud computing, big data, artificial intelligence (AI), and the Internet of Things (IoT). Additional technologies under rapid development include virtual reality (VR) and augmented reality (AR). The scale, speed, significance and impact of these technologies on life and work are unprecedented in human history. The changing nature of work as a result of advancements in technologies affects more people faster than ever before. Digital transformation technologies can and should be applied to teaching and learning to augment and enhance the classroom, out-of-classroom, and online learning experience. The goal is to enhance student learning and student engagement at scale. For faculty, they will have the tools, support and capabilities to implement digital technologies in classrooms, labs, and online. Automation will be applied to the aspects of teaching that will remove some of the repetitive and basic labor of teaching so that instructors can focus more of their time on engaging with their students.

Generative AI can improve engineering education and the practice of engineering. We need to embrace this technology for its potential to enhance creativity and effectiveness and ensure its equitable distribution while guarding against its misuse.

With the advancement of digital transformation tools, new forms of content presentation and interaction between learners, content, and instructors can be afforded. Such technological affordances can support learners' educational experiences by promoting social, cognitive, and teaching presence in new, authentic ways.[97] *Social presence* refers to learners' ability to present themselves and be perceived as real people through communication media.[98] Interactive and collaborative technologies, such as virtual reality, augmented reality, and extended reality, can support forms of social presence. Multiuser and collaboration affordances can blur the boundaries between learning modalities. For instance, cloud-based collaboration platforms

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[97] Fiock, H. (2020). Designing a Community of Inquiry in Online Courses. *The International Review of Research in Open and Distributed Learning*, *21*(1), 134–152. https://doi.org/10.19173/irrodl.v20i5.3985

[98] Richardson, J., & Lowenthal, P. (2017). Instructor Social Presence: Learners' Needs and a Neglected Component of the Community of Inquiry Framework. *Social Presence in Online Learning: Multiple Perspectives on Practice and Research*. https://scholarworks.boisestate.edu/edtech_facpubs/206/

have paved their way into higher education, supporting in-person, online, and HyFlex modes of learning. Such platforms provide real-time collaboration and communication through web meetings, file sharing, and small-team communication channels. Similarly, multi-user virtual and gaming environments can support more complex forms of collaborative learning, such as those occurring in the engineering laboratory. *Cognitive presence* refers to learners' ability to construct meaning through continuous reflection.[99] Interactive and immersive technologies can support meaning-making processes through new forms of presentation and interaction. For instance, complex interactions and abstract conceptualizations can be made more accessible through XR, including virtual, augmented, and mixed reality, each providing different forms of immersion and augmentation. These technologies can enable forms of embodied learning, making abstract content more accessible.[100] Finally, *teaching presence* refers to the design, facilitation, and orchestration of the social and cognitive processes.[101] Advances in AI can help facilitate teaching presence by personalizing the learning experience through predictive and adaptive content and scaffolding. AI can also support feedback and tutoring processes potentially afforded by generative AI.

The application of digital transformation technologies is to be centered around these teaching and learning practices:

- Student formative and summative assessment and predictive analytics
- Personalized and adaptive student learning experience
- Classroom and out-of-classroom (example; independent student project work) learning experience
- Enhanced experiential classroom and laboratory learning experience
- Virtual laboratories
- Enhancement of online learning experience
- Faculty course management
- Equity and fairness embedded and studied in the use of educational technology

While the opportunities for teaching and learning enabled by emerging technologies have promising outcomes, the role of the instructor is critical in promoting, facilitating, and orchestrating social, cognitive, and teaching presence processes. Similarly, adopting or adapting these emerging technologies should also be designed considering learner-centered approaches, universal design principles, and, whenever possible, designed through participatory approaches to ensure that the technologies will truly serve the needs of the learners. Finally, aspects of access, affordability, and equity are important considerations.

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[99] Garrison, D. R., Anderson, T., & Archer, W. (2001). Critical thinking, cognitive presence, and computer conferencing in distance education. American Journal of Distance Education, 15(1), 7–23

[100] Lindgren, R., & Johnson-Glenberg, M. (2013). Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality. *Educational Researcher, 42*(8), 445–452

[101] Garrison, D.. (2007). Online community of inquiry review: Social, cognitive, and teaching presence issues. Journal of Asynchronous Learning Networks. 11. 10.24059/olj.v11i1.1737.

CHAPTER 5. An Inclusive and Diverse Engineering Education Learning Environment

Historical and contemporary harm systematically marginalizes and excludes people from engineering, creating systems of advantage and disadvantage that privilege some and oppress others. We must collectively acknowledge and address these systems by removing barriers and adding support to create a more equitable and inclusive engineering education. This effort is an inclusive mindset in practice. Doing this creates more welcoming environments, or structural belonging, where people feel valued, included, encouraged, and affirmed. There are five distinct yet interrelated recommendations for creating environments designed for everyone's success:

1. Practice Systems Thinking
2. Reflect on Positionality
3. Engage in Lifelong Learning
4. Identify Humanized Pedagogy
5. Hold Stakeholders Accountable (Addressed in Chapter 7 of the report)

Why do we need a welcoming learning environment?

The learning environment encompasses every element of where learning happens. It includes the labs, classrooms, and every aspect of higher education, including the physical spaces between and around the classrooms and all interactions, each potentially representative of the engineering ethos. One can ascertain an institution's engineering ethos or culture and mindset by observing how administrators, faculty, staff, and other university employees engage with one another, how they treat students and student workers, and vice versa, and by noticing what is taught, rewarded, or ignored.

Wright et al[102] summarized: "The engineering learning environment has been described as 'suffering and shared hardship'[103], a 'meritocracy of difficulty'[104], and an overall 'culture of

[102] Wright, C. J., Wilson, S. A., Hammer, J. H., Hargis, L. E., Miller, M. E., & Usher, E. L. Mental health in undergraduate engineering students: Identifying facilitators and barriers to seeking help. *Journal of Engineering Education*. https://doi.org/10.1002/jee.20551

[103] Godfrey, E., & Parker, L. (2010). Mapping the cultural landscape in engineering education. *Journal of Engineering Education*, 99(1), 5–22. https://doi.org/10.1002/j.2168-9830.2010.tb01038.x

[104] Stevens, R., Amos, D., Jocuns, A., & Garrison, L. (2007). *Engineering as lifestyle and a meritocracy of difficulty: Two pervasive beliefs among engineering students and their possible effects*. Paper presented at the ASEE Annual Conference and Exposition, Honolulu, HI. https://doi.org/10.18260/1-2--2791

stress'."[105,106] Research has shown that the learning environment is one critical component that causes students to leave STEM fields. The groundbreaking work by Seymour & Hewitt[107] and the 20-year follow-up analysis[108] have confirmed the pervasive and persistent systemic issues associated with "poor teaching, poor curricular design and the negative climate of STEM."[77.78] For students who left STEM fields and for students who remained, the most reported concern was the "competitive, unsupportive STEM culture makes it hard to belong. " As described further in the forward, Shirley Malcom stated:

> There is evidence to support the idea that the normative culture of science includes the view that natural ability determines the capacity for STEM learning; many of the faculty within STEM exhibit a "fixed ability mindset." This would mean that as early as possible their role would be perceived as that of "identifying the best and weeding out the rest"; … the structured intentionality of the weed-out system [is] to get rid of a higher proportion of them [students] rather than teach them. … Other aspects of the negative impact of the culture of STEM include gender stereotyping and bias against students of color. I found it sad that women of color still felt safer approaching graduate TAs for assistance (rather than faculty) 50 years after I made that same choice following a similar assessment. And they likely made that decision for the reason that I did—to avoid experiencing the bias associated with not belonging. (p. vii)[78]

A student's sense of social belonging has been connected with student persistence and learning. [109,110,111] By the same token, a sense of being devalued in the engineering community, disrespected on campus, or unwelcome in the discipline can be a strong barrier to learning. While there are several factors (i.e., grades and climate) that contribute to a student's decision to leave, students who are typically the most underrepresented in STEM fields depart. Specifically, women switch out of STEM at higher rates than men (18% for women compared to 11% of men) and marginalized (i.e., African American, Native American, Hispanic/Latino, or

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[105] Cross, K. J., & Jensen, K. J. (2018). *Work in progress: Understanding student perceptions of stress as part of engineering culture*. Paper presented at the ASEE Annual Conference and Exposition, Salt lake City, UT. https://doi.org/10.18260/1-2--31312.

[106] Jensen, K. J., & Cross, K. J. (2021). Engineering stress culture: Relationships among mental health, engineering identity, and sense of inclusion. *Journal of Engineering Education*, 110(2), 371–392. https://doi.org/10.1002/jee.20391

[107] Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving* (Vol. 34). Westview Press, Boulder, CO.

[108] Seymour, E., Hunter, A. B., & Harper, R. P. (2019). Talking about leaving revisited. *Talking About Leaving Revisited: Persistence, Relocation, and Loss in Undergraduate STEM Education*.

[109] Hausmann, L. R., Ye, F., Schofield, J. W., & Woods, R. L. (2009). Sense of belonging and persistence in White and African American first-year students. *Research in Higher Education*, *50*, 649-669.

[110] Hurtado, S., & Carter, D. F. (1997). Effects of college transition and perceptions of the campus racial climate on Latino college students' sense of belonging. *Sociology of education*, 324-345.

[111] Walton, G. M., & Cohen, G. L. (2011). A brief social-belonging intervention improves academic and health outcomes of minority students. *Science*, *331*(6023), 1447-1451.

Native Hawaiian/Pacific Islander) leave at higher rates than non-URMs (20% for URMs compared to 13% for non-URMs).[112]

Recommendations: An Inclusive and Diverse Engineering Education Environment

Practice Systems Thinking

To create welcoming environments, engineers must understand, identify, and address how systems create inequities through the systematic oppression of traditionally marginalized and excluded groups. Systems are designed by people and upheld by people, whether intentionally or not. Ultimately, there are both systems of advantage (privilege) and disadvantage (oppression). Systems are always at play in communities, institutions, and classrooms. As in many healing practices, we must first admit we have a problem, identify root causes, and take meaningful action for sustainable change. In this section, we describe what we mean by systems, who the traditionally marginalized and excluded groups are, and propose a model for revealing and understanding the systematic oppressions these groups face in engineering education.

> *"We cannot address what we do not acknowledge, it [is] now imperative that [systemic racism] be acknowledged by those with the power to impact the process."*[113]

Engineering education, and higher education in general, were originally designed for those who were allowed access, predominantly White, able-bodied, heterosexual men with economic means.[114] Learning environments and academia remain microcosms of society, manifesting privilege and reinforcing power dynamics throughout the educational system. Cech finds that white men experience more social inclusion, professional respect, and career opportunities and have higher salaries and persistence intentions than STEM professionals in 31 other intersectional groups.[115] Holly presents evidence that anti-Black racism is embedded in engineering culture.[116] Pawley's work examines how various ruling relations incorporated in universities and engineering colleges and schools help structure engineering education as a

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[112] Weston, T. J. (2019). Patterns of switching and relocation. *Talking about leaving revisited: Persistence, relocation, and loss in undergraduate STEM education*, 55-85.
[113] Coley, B.C., Simmons, D.R. and Lord, S.M. (2021), Dissolving the margins: *LEANING IN*to an antiracist review process. J Eng Educ, 110: 8-14. https://doi.org/10.1002/jee.20375
[114] Wulf, W.A. 1998. Diversity in engineering. *The Bridge* 28(4):8–13. https://www.nae.edu/7488/DiversityinEngineering
[115] Cech E.A. 2022. The intersectional privilege of white able-bodied heterosexual men in STEM. *Science Advances* 8(24). DOI:10.1126/sciadv.abo1558
[116] Holly Jr., J. 2020. Disentangling engineering education research's anti-Blackness. *Journal of Engineering Education* 109(4):629–35. https://doi.org/10.1002/jee.20364

raced and gendered discipline, and offers insights to help readers inquire into the structure of their own organizations.[117]

Recommendation 3.1: Evaluate the systems in place in our engineering and engineering technology programs and make changes that will create a fair and equitable system for all students.

The higher education system or structure includes admissions, testing, advising, policies, procedures, norms, curriculum, financial aid, culture/climate, degree plans, grading standards, promotion and tenure of faculty/staff, research, and job placements, among others. Each of these systems and its parts can (and should) be independently and regularly evaluated to determine who's being best served and who isn't. When these data are disaggregated by a multitude of demographics and overlapping (intersectional) identities, inequities and patterns of exclusion and marginalization are revealed.

Women, Blacks, Hispanics, Indigenous people, some Asian groups, people with disabilities, nonheterosexuals, and people from low socioeconomic groups have been traditionally marginalized and excluded from engineering. The root causes are numerous and complex, and each is a function of a system. Decades of research aim to increase understanding of the root causes, and yet there is no simple solution to the issues because the systems are intertwined, interdependent, and complicated. There is hope, however.

Understanding and designing systems is a key tenet of engineering. According to ABET, "Engineering design is a process of devising a system, component, or process to meet desired needs and specifications within constraints."[118] In addition, engineers must be systems thinkers, able to view systems from a broad perspective, seeing structures, patterns, and cycles rather than a single event, condition, or circumstance. Extrapolating this skillset away from "widgets" and focusing on work and learning places and spaces, engineers have the potential to be stellar systems thinkers who intentionally create welcoming environments for all. To do so, we must practice systems thinking to identify the barriers others face, remove them when possible, and provide equitable support that levels the playing field.

Systems thinking requires seeing how outcomes are connected to and products of a system. For example, research shows that self-efficacy[119] and stereotype threat[120] are influential factors

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[117] Pawley, Alice. 2019. Learning from small numbers: Studying ruling relations that gender and race the structure of US engineering education. *Journal of Engineering Education* 108:13–31. https://doi.org/10.1002/jee.20247

[118] https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2023-2024/#GC3

[119] Self–efficacy is one's belief that they can be successful in a specific task or challenge, and answers the question: "Can I do this?" An individual with high self–efficacy is more likely to adopt and commit to more challenging goals, and an individual with low self–efficacy is more likely to avoid challenges. Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. Psychological Review, 84, 191-215.

[120] Stereotype Threat: A socially premised psychological threat that arises when one is in a situation or doing something for which a negative stereotype about one's group applies. Steele, C. M., & Aronson, J. (1995).

in women's decision not to enter or persist in engineering.[121] These are both internalized oppressions that are directly impacted by external factors grounded in persistent ideologies that manifest in interactions and are embedded in institutions. Too often, efforts stop at outcomes like low self-efficacy and do create programs to support students' development. However, without addressing the systemic contributions that reduce self-efficacy, the problem will persist because it is a function of the external systems.

Reflect on Positionality

This recommendation focuses on the individual players within the systems through the practice of positionality, the social and political context that creates one's identity and how it influences and biases one's perception of and outlook on the world.[122]

Positionality is ever-present, affecting all aspects of our lives, including teaching, leading, policymaking, everyday interactions, and research – where the concept is most often prevalent. Secules et al.[123] found that positionality impacts six fundamental aspects of research: research topic, epistemology, ontology, methodology, relation to participants, and communication, and made a case for positionality as a necessary aspect of engineering education research.[104]

Recommendation 3.2: Offer professional development on positionality for faculty in order to raise awareness of one's identity and how it influences a person's teaching and everyday interactions.

Positionality is a reflexive exercise to examine who we are and how we are situated within and thus participate in systems. Simply put, it is an investigation of power, privilege, and position, or the lack thereof.[124] Ultimately, it involves a personal and collective effort to reveal the power relations between groups, acknowledging privilege or marginalization, and making choices to reduce how power structures perform.

For example, if a White male (or person with any element of privilege) professor, student, or administrator looks around their engineering environment and says, "I don't understand what [marginalized people] are complaining about, my experience is perfectly fine," they are not reflecting on their positionality. When positionality is considered, this person might identify that their privilege grants them a different experience in engineering and that they may not face or even see the barriers faced by marginalized people. People from marginalized groups also benefit from reflecting on positionality. For example, if a person from a marginalized

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Stereotype threat and the intellectual test performance of African Americans. Journal of Personality and Social Psychology, 69(5), 797–811. https://doi.org/

[121] Hill, Catherine. 2010. *Why So Few? Women in Science, Technology, Engineering, and Mathematics*. Washington: AAUW.

[122] https://engineerinclusion.com/what-is-positionality/

[123] Secules, S., McCall, C., Mejia, J. A., Beebe, C., Masters, A. S., Sánchez-Peña, M. L., & Svyantek, M. (2021). Positionality practices and dimensions of impact on equity research: A collaborative inquiry and call to the community. *Journal of Engineering Education*, *110*(1), 19-43. https://doi.org/10.1002/jee.20377

[124] Learn more: https://nmaahc.si.edu/learn/talking-about-race/topics/social-identities-and-systems-oppression

population has deeply internalized oppressions (as noted in the discussion on systems), they might have a view of exceptionalism that has blinded them from the numerous barriers they have faced and overcome, and say something like, "nobody helped me, and I did just fine." A reflection on positionality (power, privilege, position) might uncover uncomfortable and painful truths of survival in unwelcome environments, or it might reveal unexpected elements of privilege and support.

To create welcoming environments, we must regularly reflect on how social and political contexts create our identities; how those identities create power dynamics that must be acknowledged, carefully monitored, and reduced: how privilege influences access and opportunity: and the need for intentional choices to make space for those who have been traditionally marginalized and excluded in engineering. In response to power, privilege, and position, an earnest progression from awareness to action can yield an equitable and inclusive environment for all.

Engage in Lifelong Learning for Faculty to Engage in Understanding Inclusive and Equitable Teaching Practices

Designing welcoming classroom environments that foster belonging and equitable outcomes for all students requires a commitment by educators to continuously learn about best practices for inclusive and equitable teaching and to examine student data to better interpret how institutional structures (or systems) affect educational outcomes. As educators apply their learning to their particular teaching contexts, they must continue to revise and refine their strategies, policies, and mindsets. Creating welcoming educational spaces inside and outside the classroom that are designed with equitable and inclusive teaching practices requires continual professional development for engineering and engineering technology faculty and staff. In the same way that lifelong learning is an expectation for engineering and engineering technology students, it is also necessary for instructors to foster faculty mindsets that support learning environments that benefit all students.

Recommendation 3.3: Provide professional development for faculty and staff to foster development of a mindset that centers on lifelong learning to support faculty's understanding of inclusive and equitable teaching practices.

Fostering welcoming learning environments requires continuous learning about best practices for inclusive and equitable teaching while also gaining insights into student experiences and their educational outcomes. The mindset that centers on lifelong learning to support faculty's understanding of inclusive and equitable teaching practices and the examining of institutional data has the potential to shift engineering culture within respective institutions in profound ways. There will be institutional support for individual lifelong learning in this proposed environment, regardless of the institutional type and faculty role. Further, these programs would be designed to leverage best practices that motivate adult learning, such as expert presenters, relevant content, choice in the application, praxis (i.e., action and reflection), and group work.[125, 30]

With this mindset, faculty will be equipped to create sustainable, welcoming environments that can adapt to the needs of their student populations. Students who have largely been excluded from engineering will have a greater sense of belonging, and their presence will become commonplace. With a broader population working in the engineering profession (and beyond), engineering solutions will better reflect society's needs and imaginations.

Identify Humanized Pedagogy

The next interrelated step within this recommendation is to identify and employ a humanized socio-technical pedagogy. Engineering education has historically emphasized technical more so than social components (i.e., humans, humanity, and the impact on society). Strong beliefs and actions persist, such as, "I'm just here to teach [engineering subject]" or "Engineering isn't biased, it's just engineering," or the weed-out culture[126] that prioritizes exclusion. Attitudes and practices that do not center on students and their experiences but instead prioritize the curriculum's technical aspects create a dehumanizing environment. To dehumanize is to deprive something, in this case engineering and its environment, of positive human qualities.

The following summary of Wright et al.'s analysis[127] considers the mental health of engineering students and whether it is prudent to persist in a dehumanized engineering learning environment:

> Students can experience stress related to an unsupportive and challenging learning environment, challenges in time management, and academic performance expectations.[128] This culture of stress, which is often normalized in engineering[129], can negatively impact students' mental health. Several studies have aimed to quantify the prevalence of mental health distress among engineering students, and results have varied by population. Of significant concern, higher rates of mental health distress have

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[125] Wlodkowski, R. J. (1999). *Enhancing adult motivation to learn: A comprehensive guide for teaching all adults*, 2nd ed. New York, NY: John Wiley and Sons.

[126] Wallwey, C., Guanes, G., Milburn, T., and Grifski, J. 2022. Engineering and Exclusionary 'Weed-Out' Culture: A Framework for Exploring Literature for Meaning and Influence. Paper presented at 2022 ASEE Annual Conference and Exposition, Minneapolis, MN. https://peer.asee.org/41070

[127] Wright, C. J., Wilson, S. A., Hammer, J. H., Hargis, L. E., Miller, M. E., & Usher, E. L. Mental health in undergraduate engineering students: Identifying facilitators and barriers to seeking help. *Journal of Engineering Education*. https://doi.org/10.1002/jee.20551

[128] Ban, N., Shannon, H., Wright, C. J., Miller, M. E., Hargis, L. E., Usher, E. L., Hammer, J. H., & Wilson, S. A. (2022). *Identifying common perceived stressors and stress-relief strategies among undergraduate engineering students*. Paper presented at the ASEE Annual Conference and Exposition, Minneapolis, MN.

[129] Beddoes, K., & Danowitz, A. (2022).In their own words: How aspects of engineering education undermine students' mental health. Paper pres-ented at the ASEE Annual Conference and Exposition, Minneapolis, MN.982WRIGHTET AL.

been found in female and first-generation,[130] as well as gender-expansive engineering students.[131] In addition, engineering students who viewed their classrooms as competitive were more likely to suffer from anxiety and depression.[132] These adverse effects were more pronounced for students with marginalized identities, specifically female-identified and Black engineering students. This signals the importance of studying mental health in engineering, especially in marginalized student populations.

The pattern of dehumanization most often leads to a deficit framework to explain why traditionally marginalized and excluded populations do not thrive in engineering, suggesting that they lack the skills needed to succeed or cultural differences are perceived as detrimental to the learning environment. A deficit mindset does not consider systems thinking. Conversely, an asset framework considers how the system resulted in the outcomes and recognizes students' cultural differences as beneficial to the learning environment. Therein lies a choice. A humanized environment welcomes students and their lived experiences as co-creators of their learning by valuing and affirming their identities.

Recommendation 3.4: Modify engineering curricula to emphasize a humanized socio-technical framework.

This is a major shift in mindset away from standard or normative engineering values of process, order, efficiency, and earnings. However there is a history of movements within education toward student-centered, culturally responsive, active learning and evidence for the benefit of student performance and retention.[133,134,135,136] Humanized pedagogy is the planning and implementation of pedagogical practices that are aligned with learner experiences and perspectives.[137] It honors, values, and represents multiple ways of knowing, doing, and being,

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130 Jensen, K. J., & Cross, K. J. (2021). Engineering stress culture: Relationships among mental health, engineering identity, and sense of inclu-sion.Journal of Engineering Education,110(2), 371–392.https://onlinelibrary.wiley.com/doi/10.1002/jee.20391

131 Hargis, L. E., Wright, C. J., Usher, E. L., Hammer, J. H., Wilson, S. A., & Miller, M. E. (2021).Relationship between mental health distress andhelp-seeking behaviors among engineering students. Paper presented at the ASEE Virtual Annual Conference Content Access. https://peer.asee.org/37657

132 Posselt, J., & Lipson, S. (2016). Competition, anxiety, and depression in the college classroom: Variations by student identity and field ofstudy.Journal of College Student Development,57(8), 973–989. https://muse.jhu.edu/article/638561

133 Felder, R. M. (1995). A Longitudinal Study of Engineering Student Performance and Retention. IV. Instructional Methods. *Journal of Engineering Education*, *84*(4), 361-367. https://doi.org/10.1002/j.2168-9830.1995.tb00191.x

134 Jordan, S. S., Foster, C. H., Anderson, I. K., Betoney, C. A., & D. Pangan, T. J. (2019). Learning from the experiences of Navajo engineers: Looking toward the development of a culturally responsive engineering curriculum. *Journal of Engineering Education*, *108*(3), 355-376. https://doi.org/10.1002/jee.20287

135 Drake, R., Poleacovschi, C., Faust, K. M., True-Funk, A., & Kaminsky, J. (2023). Civil engineering students as avoidant actors: Using culturally relevant problem-solving to increase critical action attitudes. *Journal of Engineering Education*, *112*(2), 262-283. https://doi.org/10.1002/jee.20507

136 Cleave, N. V. (2001). Components of an American Indian Computer Science Transfer Degree Program*. *Journal of Engineering Education*, *90*(1), 55-61. https://doi.org/10.1002/j.2168-9830.2001.tb00567.x

137 Fredricks, Daisy & Peercy, Megan. (2022). Multilingual Youth Perspectives on Humanizing Core Practices. 10.4018/978-1-6684-3690-5.ch065.

incorporating funds of knowledge[138,139,140] from traditionally marginalized and excluded populations. For engineering to be welcoming to every student, the course curriculum, and the implicit cultural curriculum (everything in and beyond the coursework), must be anti-racist, feminist, and intentionally inclusive. A humanized pedagogy provides equity that balances the systemic issues at play in any given environment.

A Human-Centered Design of Engineering Education

We call for a human-centered design of engineering education. Buchanan writes, "Human-centered design is fundamentally an affirmation of human dignity. It is an ongoing search for what can be done to support and strengthen the dignity of human beings as they act out their lives in varied social, economic, political, and cultural circumstances."[141]

Recommendation 3.5: Expand user-centered design practices common within engineering to a whole student-centered design of learning environments (where whole means students' comprehensive identities and experiences are valued, included, and affirmed).

When educators make an effort to identify a humanized pedagogy that prioritizes students over content, that draws from an asset rather than a deficit framework for the contributions of students, every student will benefit, and those from traditionally excluded and marginalized are more likely to experience feelings of belonging.

Advance an Anti Racist Pedagogy

There is a lack of acknowledgment of the racist US history that permeates higher education and the field of engineering. This lack of acknowledgment leaves no room for investigation of the role of engineering administrators, faculty, staff, and students in the persistence of racism and inequity in the STEM culture. Unfortunately, DEI efforts are seen as separate from the educational mission of STEM. This demarcation, compounded by the lack of acknowledgment, prevents members of the STEM community from thinking of DEI as a design issue with challenges and opportunities that can be countered with a systems thinking perspective. DEI and STEM education are further separated because STEM is presented as apolitical and neutral or agnostic to the society in which it exists.

The antiracist approach to STEM education would require explicitly connecting STEM technical content to DEI work (e.g., scholarship and research) in the context of learning environments, communities, society, and the world. These connected and interrelated institutions (e.g.,

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[138] Verdín, D., Smith, J. M., & Lucena, J. C. (2021). Recognizing the funds of knowledge of first-generation college students in engineering: An instrument development. *Journal of Engineering Education*, *110*(3), 671-699. https://doi.org/10.1002/jee.20410

[139] Svihla, V., & Chen, Y. (2022). A funds of knowledge approach to developing engineering students' design problem framing skills. *Journal of Engineering Education*, *111*(2), 308-337. https://doi.org/10.1002/jee.20445

[140] Wilson-Lopez, A., Mejia, J. A., Hasbún, I. M., & Kasun, G. S. (2016). Latina/o Adolescents' Funds of Knowledge Related to Engineering. *Journal of Engineering Education*, *105*(2), 278-311. https://doi.org/10.1002/jee.20117

[141] Buchanan, R. (2001). Human Dignity and Human Rights: Thoughts on the Principles of Human-Centered Design. *Design Issues, 17*(3), 35-39. doi:10.1162/074793601750357178

education and economics) will then inform what we teach, who we teach, and how we teach. STEM antiracist pedagogy will integrate facilitated dialogues about the intersections of race, class, gender, power, and STEM education. It will require educators to teach authentically,[142] acknowledge power dynamics and the multiple intersecting identities of learners and educators, and create spaces for all to explore how their social and cultural identities will impact the future of engineering.

The following assumptions underlie our recommendations:

- Acknowledge the racist history of the US educational system and how it impacts current educational epistemologies and pedagogical practices.
- Elevate all non-centered identities. This decentering is the basis of all our recommendations.
- Address everyone but focus on where each person has a sphere of influence or level of control. This includes those focusing on theory and DEI research, ABET, ASEE, and NAE, practicing educators, and engineering students, among others.
- Implement policy and behavioral changes to support the recommendations.
- Develop and implement clear assessment tools and accountability measures defined in a local context and associated with each recommendation.

Recommendation 6: Integrate trauma-informed and healing-informed practices in engineering culture and education, with a focus on racialized trauma.

This recommendation highlights the importance of educating the entire engineering community on trauma and healing. Increasing awareness of how trauma manifests, how it impacts actions/behaviors, and how healing pedagogy through trauma can be supported will create innovative teaching and learning strategies for ways to support students, faculty, and staff (this recommendation is related to the fourth recommendation). Through healing, the engineering community will more likely be able to bring their full authentic selves to the field and, particularly, the learning environment.

This recommendation brings two impactful lenses that have not been prominent but are potentially transformative for engineering education: trauma and healing. With this recommendation, we are highlighting the importance of educating the community on trauma and healing. Increasing awareness of issues in this recommendation—how trauma manifests, how trauma impacts action, and how healing can be supported—will create new ideas for supporting all students. This recommendation is related to Recommendation 4 in that through healing, educators & students will be able to be their whole, full, authentic selves.

[142] Authentic teaching emphasizes interconnected knowledge and knowledge in context involving the application of multiple perspectives, multiple knowledge sources, multiple points of view.

Recommendation 7: Accept that engineering is a body politic (political science definition related to power and privilege) and establish policies that define individual and collective accountability

Engineering needs to acknowledge its role as a historical site of male patriarchy that enabled White supremacy and work to establish policies that define individual and collective accountability regarding racial equity. We recommend leveraging the political power of the engineering education community through ASEE to improve how US institutions are measured and viewed by stakeholders, including parents and students. Engineering is not strictly a technical discipline operating without human biases and sensibilities. We must acknowledge, accept, and leverage the power and privilege that engineering and engineers hold to counter racist societal norms. We recommend, as a first step, that ASEE update its ranking system based on these values of equity and transparently share data with other organizations. More robust accountability measures are needed among scholars who will both challenge and publicly support each other in efforts to promote racial equity.

Recommendation 8: Include professional development in the framework of historical events and structures that continue to shape societal inequities.

We recommend a rethinking of how engineers are trained and what they are prepared to do. Engineering student programs are currently focused on technical training with little consideration of applications and impacts until later in their studies. Educators and students need a better understanding of the historical events and structures that shape societal inequities. There is a need to improve educators' and students' understanding of their biases based on socialization and experiences and how these biases can impact our judgment and decision-making and limit our ability to solve the societal problems we face equitably. We recommend elevating consideration of the impacts of engineering on human lives and integrating this type of design thinking throughout the engineering curricula. We also recommend acknowledging and celebrating educators who are already engaged in teaching and research efforts to share successful strategies. This recommendation elevates the work of a specific “end user”: educators.

Recommendation 9: Create an engineering antiracist pedagogy that intentionally integrates antiracism into what is taught and how.

We recommend that the engineering education community develop an antiracist pedagogy as a guiding principle and practice to integrate antiracism into what is taught and how. Engineering-specific antiracist pedagogy considers engineering education’s history, epistemology, and goals to highlight policies, practices, and processes specific to engineering education. This involves educators committed to understanding who we are as teachers and who our students are. This requires an educational approach that is recentered or refocused on personhood to bring our authentic selves into the learning environment to humanize engineering education.

In summary, a welcoming environment is a foundational step toward creating the engineering mindset of the future. To do so, the engineering and engineering technology community should intentionally practice systems thinking, reflect on positionality, engage in lifelong learning, identify humanized pedagogy, and expand design practices to include a whole student-centered design. These actions provide the basis for our remaining recommendations associated with revising curricula to remove barriers, applying research-based and authentic teaching methods, developing institutional structures to serve our students, and leveraging strategic partnerships.

The authors of this report understand the political challenges higher education leaders and faculty face in addressing DEI and racial inequities. Some states legislatures are hostile to anything related to DEI and others states are supportive. For those individuals and leaders wishing to pursue DEI and racial inequities, we suggest following the recommendations in the NASEM report on Advancing Antiracism, Diversity, Equity, and Inclusiong in STEMM Organization: Beyond Broadening Participation.[143]

[143] National Academies Of Sciences Engineeri, and, E., And, B., and, B., Board, Board, & Stem, in. (2023). *Advancing Antiracism, Diversity, Equity, and Inclusion in Stemm Organizations: Beyond Broadening Participation*. National Academies Press.

CHAPTER 6. Preparing Campuses for a Student-Centered Engineering Education

The creation of flexible and inclusive institutional and regulatory structures that foster student success will depend on allowing for rapid innovation and adaptation in learning and teaching approaches that serve all students, staff, and faculty, particularly groups who have been historically excluded from the engineering profession. Institutional structures should serve as bridges rather than constraints, expand horizons, make destinations visible, and allow swift access to careers and personal fulfillment.

The Role of Institutional Change to Realize Large-Scale Change in Engineering Education

An inclusive excellence ecosystem, "operating across varied contexts with a shared goal of driving change in the demographics of STEM, requires experienced leaders; mutually reinforcing partnerships; the involvement of local, regional, and national communities; crosscutting organizational structures and behavior (e.g., norms, consensus building, models of collegiality, defined core values) to support students; and the intentional development of future leaders."[144]

Creating structures that support innovation and allow for diverse, equitable involvement in engineering education requires removing institutional barriers and modifying processes and procedures at the university and college levels. Because change is difficult, it is essential to be intentional and incorporate accountability. Consideration of admission processes and transfer pathways requires institutional-level networks that consider equity, access, and preparation that motivate and engage students. Building a culture of innovation that supports the ongoing use of contextual best practices and adaptation to new challenges and experiences means (a) considering local culture to address racist and oppressive structures that may hamper the full involvement of all faculty and (b) addressing policies that limit hiring, retention, and motivation of faculty. Policies that constrain institutions and their processes, technical systems that overly constrain course offerings and registration, and institutional governance approaches that limit innovation and funding policies should be examined regularly to ensure inclusion and to remove biases. At the institutional level, curricular structures and the datasets that constrain them should allow for modularity variation, prior learning evaluation, and a broad range of

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[144] Payton, Fay Cobb, and Ann Quiroz Gates. "The Role of Institutional Leaders in Driving Lasting Change in the STEM Ecosystem." *Issues in Science and Technology* 39, no. 4 (Summer 2023): 73–80. https://doi.org/10.58875/KRUL4399

learning and assessment approaches. Addressing institutional structures in multiple ways will provide pathways for ongoing innovation and improvement in engineering education.

Strategies include the following:

- Be intentional about large-scale change in engineering education.
- Create structures that facilitate increased pathways to and through engineering degrees.
- Assess and reimagine institutional culture to support access, equity, and innovation.
- Review and revise institutional policies, practices, and structures to enable and encourage effective and equitable innovation.

Be Intentional about Large-Scale Change

Developing a student-centered, innovative, adaptive, robust, diverse, and inclusive engineering curriculum requires intentional *large-scale change*. For lasting impact and long-term success, reforms must be implemented on a scale that involves multiple engineering schools, professional organizations, industry partners, accreditation agencies, and government agencies. A collaborative approach is necessary to foster the creation of a collective knowledge base, enabling institutions to learn from each other and continuously improve their educational offerings. Large-scale change will involve developing, validating, and disseminating best practices across institutions and will benefit from experts in change processes and management. Maintaining change will require multiple points of accountability and reflection. Multiple stakeholders within and outside institutions must be involved and work together to address challenges in modernizing engineering education, sharing insights, experiences, and successful strategies. Large-scale change has the potential to create a ripple effect: As more institutions adopt innovative teaching methods, fair assessment strategies, and curricular designs, the pressure to evolve and adapt will increase for those still adhering to traditional approaches. This momentum will drive systemic change, making engineering education more resilient and responsive to the evolving needs of students and society.

Government and accrediting agency support are vital for achieving this large-scale change. Recognizing the importance of engineering education reform, government agencies can provide funding, incentives, and policy support to facilitate the implementation of new initiatives. They should allocate funding for institutions that commit to transformative changes in their curricula and teaching methods. Policy support should be provided for revising or updating funding and accreditation standards to encourage the adoption of student-centered, innovative, and inclusive approaches to education. Accreditation bodies will need to promote a more flexible set of guidelines, enabling engineering schools to implement changes to ensure that engineering education remains relevant, adaptive, and capable of meeting the needs of students, industry, and society. Institutions should reflect on and change structures that are barriers to innovation, including reward structures that drive faculty hiring, tenure, and promotion, as well as structures related to governance, curricular approvals, financial aid, collaborative teaching, and student registration and records.

Institutions are responsible for creating an environment that encourages risk-taking and experimentation for the benefit of all. This is a needed culture shift, where failure is seen as an opportunity for growth and learning. Institutions can help foster a culture of continuous improvement and innovation. Finally, large-scale change in engineering education cannot be achieved through one-off training sessions or short-term initiatives. Institutions must demonstrate a sustained commitment to the necessary changes for innovation.

Create Structures to Enable and Encourage Effective, Equitable, and Innovative Pedagogical Approaches

For a systemic change in engineering education, institutional structures must be reconstructed to enable and encourage faculty to adopt effective, equitable, and innovative pedagogical approaches. The literature has illuminated the value of student-centered and inclusive teaching practices, including active learning, mastery-based assessment, and project-based learning, among others, but, while faculty individually implement and innovate in their classrooms, widespread adoption of these pedagogies continues to be elusive.

At all scales—individual programs and departments, institutions, professional societies, accrediting bodies, and government—curricular structures must be critically reconsidered to center student learning and enable effective and inclusive pedagogy.

Hold Stakeholders Accountable

Faculty, staff, administrators and accrediting bodies play central roles in the development of the next generation of engineers. The approaches, mindset, and culture that they all practice and establish in the curriculum have direct impacts on preparing students to be future engineers. Instituting accountability measures in how all these stakeholders (i.e., faculty, staff, and administrators) are evaluated and rewarded incentivizes the continued commitment to addressing inequities that detrimentally impact the learning environment. To support this cultural shift, institutions should consider how to best incentivize lifelong learning that reflects recommendations in the literature regarding professional development. Some incentives are providing choice, relevant content, and expert facilitators, to name a few. Accreditation should specifically prioritize faculty's lifelong learning, focusing on inclusive and equitable teaching practices while also supporting students' learning on topics related to DEI; establish processes for continuously reviewing student outcomes for inequities; and develop (or revise) program-level structures for mitigating any identified gaps.

Accountability measures to support a welcoming learning environment are unevenly available and enforced. The success of these accountability efforts often depends on institutional priorities, institutional type, faculty role, the political environment, and accreditation expectations. Accountability may come primarily in the form of requirements for individual instructors related to professional development and performance indicators associated with teaching (e.g., annual reviews, promotion & tenure processes). The presence of reward structures (e.g., DEI and/or teaching awards), can indirectly support accountability measures by providing an incentive for prioritizing efforts that would improve the learning environment for students. When reflecting on the overall institutional climate, accountability measures may also focus on “metrics to monitor student success as well as DEI”. [145]

For accreditation purposes, ABET has a student outcome for engineering student performance (Student Outcome 5) that expects students to be able to “function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.”[146] Further, ABET General Criterion 4 indicates program expectations for continuous improvement by “assessing and evaluating the extent to which the student outcomes are being attained,” and one of the factors to evaluate faculty competencies (General Criterion 6) includes “teaching effectiveness and experience.”[144] While these criteria are important initial steps, they are insufficient to bring about an institutional culture that prioritizes inclusive and equitable teaching practices, equitable performance outcomes for students, and sustained structures for ensuring that the welcoming environment that supports students’ sense of belonging is maintained.

Further efforts focusing on institutional change are “not easy to initiate, scale or sustain. When educators engage with an effort that seeks to address systemic structures, policies, practices, and beliefs that challenge inequities and the reasons why inequities exist, the work becomes even more difficult. There are no simple answers and no linear pathways to success.”[147] While this challenge exists, establishing a mindset where educators and leaders within an institution share a common vision for establishing and maintaining a welcoming and equitable learning environment and establishing accreditation expectations that more fully prioritize diversity, equity, and inclusion can potentially bring engineering programs closer to their aspirational goals.

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[145] Kezar, A., Holcombe, E., & Vigil, D. (2022). *Shared responsibility means shared accountability: Rethinking accountability within shared equity leadership*. American Council on Education. pp 5. https://www.acenet.edu/Documents/Shared-Equity-Leadership-Accountability.pdf

[146] ABET. (n.d.). Criteria for Accrediting Engineering Programs, 2022 – 2023. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/

[147] McNair, T. B., Bensimon, E. M., & Malcom-Piqueux, L. (2020). *From equity talk to equity walk: Expanding practitioner knowledge for racial justice in higher education*. John Wiley & Sons. pp. 99.

With all these recommendations, the reconstruction of curricular structures must be done with an inclusive and equity-minded lens, as more fully described in other sections of this document.

Undergraduate Student Input (Shadow Box)

To get feedback from current engineering and engineering technology undergraduate students, members of the task force were asked to recommend students from their respective programs to participate in a virtual meeting, held on October 23, 2023, with the project PI. About 25 students participated, providing their written input on three questions followed by a short discussion on each. Their responses are summarized below.

Question 1 (Likes):

Students appreciate practical, hands-on work that applies to real-world situations.

They value lab activities, active lectures, professors with industry experience and passion, and collaborative work opportunities.

They also like the career versatility of the courses, learning to solve problems from multiple perspectives, and networking opportunities.

Question 2 (Dislikes):

Students dislike poor instruction, especially from instructors who are inflexible, lack industry background, or are bad at communicating.

They are frustrated by high-stakes exams, which they feel go against engineering problem-solving principles.

The pace of courses is too fast, leading to a lack of deep understanding, and students note a delay in feedback on their performance.

They also mention a gender gap, a lack of diversity, and bureaucratic issues as significant drawbacks.

Question 3 (Improvements):

Students suggest increased flexibility in coursework and a shift from general education to major-related courses.

They want less theoretical focus, more real-world training, smaller class sizes, and enhanced career readiness initiatives.

Calls for greater inclusivity, diversity, and affordable education were prominent.

There was a general consensus that students most like hands-on/practical work dealing with real-world applications, lab activities, and active lectures. They also like working in collaborative environments that allow them to build their teamwork skills. And they appreciate professors who are passionate about engineering and engaged with their students.

What students most dislike include poor instruction, high-stakes exams that are not related to their learning, dense, inflexible curriculum, and lack of student diversity in their classes.

Improvements that students would like to see include more flexibility and choice in their coursework, fewer general education courses, fewer theory and more real-world applications, improved inclusivity and diversity, and less expensive education.

Overall, the students' experiences and recommendations align with the recommendations in this report. The inflexible and theory-based curriculum can be improved with more real-world active learning experiences in a more inclusive and diverse environment.

Recommendations: Preparing Campuses for a Student-Centered Engineering Education

Recommendation 4.1: Revise tenure and promotion processes at the department, college, and university levels to reward effort, innovation, and risk-taking in teaching.

To support and empower faculty collective action toward change, universities should create structured communities of practice for experimentation and innovation in engineering education, such as learning innovation incubators, and foster a culture of innovation and collaboration. Faculty should be encouraged to participate through incentives such as funding, release time, professional development, and recognition for innovative teaching. Such an incubator with a supportive environment will encourage experimentation and risk-taking in teaching methods and provide opportunities for faculty to share experiences and learn from one another. Formally acknowledging and elevating this type of work in the tenure and promotion process will convey to faculty that such efforts are valued by their institutions.

Recommendation 4.2: Reimagine institutional policies that support innovation in teaching and learning.

Institutional policies, structures, norms, practices, and precedents can act as supports or barriers to both innovation and inclusion in engineering and engineering technology education. Where they serve as barriers, they need to be changed. Where they serve as support, they need to be recognized and maintained. Some are extensions of federal and state policies that affect funding and accreditation, although different institutions may interpret them differently.

A review of university policies and practices can determine the root causes of inequities in the preparation of engineering and engineering technology students and lead to the identification of issues and the creation of customized systematic solutions to mitigate inequities. Systemic changes are necessary at the university level to mitigate issues. We recommend that university policies and practices be reviewed and revised to address inequities and facilitate innovation.

Recommendation 4.3: Revise program accreditation requirements to align with the changing needs of our society.

The artificial bifurcation of engineering and engineering technology does not fully acknowledge the educational preparation of engineering technology graduates and thus inadvertently limits their potential career options. BS engineering technology programs serve an essential and unrecognized role in preparing engineers. The best are more like traditional engineering programs than like technology programs that prepare technicians. The unrecognized contributions of BS engineering technology programs in preparing engineers can be partially remedied if ABET modifies the Engineering Technology Accreditation Commission (ETAC) requirements to include only BS engineering technology programs and not technicians. A new ABET accrediting option for engineering technicians would take elements of the current ETAC program to evaluate and accredit associate degree and BS programs that do not meet the enhanced standards for BS engineering technology programs. Alternatively, the Engineering Accreditation Commission (EAC) could change/reduce the (outdated) requirement of one year of math and science. Current EAC student outcomes are heavily focused on "design," while the ETAC student outcomes stress "application." That language could be modified and serve both.

Change with ABET is not enough. The higher learning commission restrictions are much more arcane and anti-innovation. These include the total number of contact hours, forcing final exam meeting time, full-time rules, and many others. Most engineering faculty and administrators are not paying attention to HLC but they work with the entire institution and hence their requirements apply to engineering as well.

ASEE and NAE should collaborate and create a strategy to approach the Higher Learning Commission to seek their support and begin to make the necessary changes that allow for a student-centered learning environment and the faculty and institutional support necessary for the transformed undergraduate engineering education as recommended in this report.

Recommendation 4.4: Work with and advocate to federal and state governments to increase flexibility in financial aid regulations, including scholarships for year-round and part-time learning.

Current federal financial aid regulations were written for a specific student: one who can approach their higher education studies as they would a full-time job, for four continuous years, without other obligations in their life. These regulations must be updated at the federal, state, and private levels to accommodate today's variety of students who wish to access engineering higher education and nontraditional evidence-based pedagogical practices. For the innovations proposed in this report to be enacted, students must be able to obtain, maintain, and apply financial aid in the following scenarios: as a part-time student (e.g., taking one course at a time or a single summer course; current eligibility requires taking at least 6 credit hours and allocation of the full Pell amount requires 12+ credit hours), after experiencing academic difficulty (minimum GPA or progress toward degree required), after changing majors or returning to higher education (limited to 180 hours in a program), as non-degree and certificate-seeking students, and for courses that are not strictly time-limited and term-based.

Recommendation 4.5: Explore and adopt a different paradigm to support an engineering mindset that fosters a culture of accountability in access and diversity.

Kezar and colleagues (2021, p. vii) propose a shared equity-leadership model:

> "in which equity becomes everyone's responsibility and multiple campus stakeholders collectively share leadership for equity. At the heart of shared equity leadership is the notion of a personal journey toward critical consciousness, in which leaders develop or strengthen a commitment to equity through their identity, personal experiences, or relationships and learning. Leaders personal journeys help them develop the values necessary to share leadership for equity, as well as carry out the practices that enact this type of leadership. These values and practices are embodied and enacted by leaders collectively.[148] "

Current federal financial aid regulations were written for a specific student: one who can approach their higher education studies as they would a full-time job, for four continuous years, without other obligations in their life. These regulations must be updated at the federal, state, and private levels to accommodate today's variety of students who wish to access engineering higher education and nontraditional evidence-based pedagogical practices. For the innovations proposed in this report to be enacted, students must be able to obtain, maintain, and apply financial aid in the following scenarios:

- as a part-time student (e.g., taking one course at a time or a single summer course; current eligibility requires taking at least 6 credit hours and allocation of the full Pell amount requires 12+ credit hours),
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- after changing majors or returning to higher education (limited to 180 hours in a program),
- as non-degree and certificate-seeking students,
- and for courses that are not strictly time-limited or term-based.

[148] Kezar, A., Holcombe, E., Vigil, D, and Matias Dizon, J.P. (2021). *Shared Equity Leadership: Making Equity Everyone's Work.* Washington, DC: American Council on Education; Los Angeles: University of Southern California, Pullias Center for Higher Education. p vii

ABET plays an important role in providing external motivation for institutions to engage in a shared-equity leadership model. For accreditation purposes, its Student Outcome 5 for engineering student performance expects students to be able to "function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives."[149] Further, ABET General Criterion 4 indicates program expectations for continuous improvement by "assessing and evaluating the extent to which the student outcomes are being attained," and one of the factors to evaluate faculty competencies (General Criterion 6) includes "teaching effectiveness and experience."[44] While these criteria are important initial steps, they are insufficient to bring about an institutional culture that prioritizes inclusive and equitable teaching practices, equitable performance outcomes for students, and sustained structures to ensure that the welcoming environment that supports students' sense of belonging is maintained.

To support the creation of such a culture, accreditation criteria could reflect the need for faculty to be aware of DEI institutional policies and inequities in society (both historical and contemporary) to inform their teaching practice. There is also an opportunity through accreditation to incorporate continuous improvement so that programs can offer evidence of efforts—including revisions to policies, practices, or the curriculum—to create a welcoming learning environment. Some of these ideas are reflected in ABET's optional pilot general criteria for accrediting engineering programs, including the revision to General Criterion 5, which calls for a curriculum that "ensures awareness of diversity, equity, and inclusion for professional practice" that aligns with the "institution's mission"; and General Criterion 6, which requires faculty to "demonstrate knowledge of appropriate institutional policies on diversity, equity, and inclusion and demonstrate awareness and abilities appropriate to providing an equitable and inclusive environment for its students, that respects the institution's mission."[44] **When ABET enforces its standards of quality, it can enable change and innovation.** For example, ABET adopted Engineering Criteria 2000 (EC2000) in the 2001–02 accreditation cycle after two years of pilots and three years of optional use. With EC2000, evaluations shifted from verifying detailed curricular specifications to verifying continuous improvement of new student outcomes in a curriculum whose specifications had been significantly reduced.[150] If ABET adopted the pilot recommendations for diversity, equity, and inclusion, then all undergraduate students and faculty would be expected to engage in learning associated with DEI. Such a

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[149] ABET Criteria for Accrediting Engineering Programs, 2022–2023. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/

[150] Prados, J.-W., Peterson, G.-D., and Lattuca, L.-R. 2005). Quality Assurance of Engineering Education through Accreditation: The Impact of Engineering Criteria 2000 and Its Global Influence. *Journal of Engineering Education,* 94(1),:165–-184. https://doi.org/10.1002/j.2168-9830.2005.tb00836.x

culture incorporates an expectation of individual accountability, which supports and rewards all in the engineering and engineering technology community.

When there is a "culture of accountability" that entrusts those in leadership to have joint equity aspirations/goals, all members of the community (faculty, staff, and students) can benefit. As described by Kezar et al.,[140] a culture of accountability that is rooted in shared equity-leadership values transparency; communication, and setting expectations; courage and humility; honesty, vulnerability, and comfort with being uncomfortable; and self-accountability. All of these are necessary when examining institutional data (e.g., climate surveys, and student outcomes) and reflecting on institutional policies, practices, and procedures that can be reimagined to better support student success in a welcoming learning environment.

When this expectation is a part of the institutional mission and the accreditation process, transformational change can occur. When there are professional development opportunities that raise awareness about student experiences, inequities they may face, and strategies for mitigating barriers, classroom and laboratory instruction can be designed (and redesigned) to foster a welcoming learning environment—for example, to reflect students' cultural context through assigned problems, with descriptions relating to real-world challenges.[151] [152]

Underrepresented students thus begin to see themselves in the instruction, and a DEI mindset is developed by all by gaining insights into the cultural experiences of others. Further, individual courses (and ultimately the curriculum) can be shaped by an intentional integration of social and technical elements in design courses as well as engineering science courses,[153] to produce engineers who are better able to deal with the complex challenges of their professional careers. Since many underrepresented minority students pursue engineering with an interest in creating solutions for social causes that correct inequities, this purposeful reimagining of the curriculum has the potential to recruit and retain these students of color.[154] And because institutional conversations about equitable outcomes can lead to practical/transformational change and professional development focusing on strategies that help foster these results, these efforts can positively impact all students, and lead to a greater potential for student success.

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[151] Gay, G. 2018. *Culturally Responsive Teaching: Theory, Research, and Practice*. Teachers College Press.

[152] Ladson-Billings, G. 2021. *Culturally Relevant Pedagogy: Asking a Different Question*. Teachers College Press.

[153] Leydens, J.-A., and Lucena, J.-C. 2017. *Engineering Justice: Transforming Engineering Education and Practice*. John Wiley and Sons.

[154] McGee, E.-O. 2021. *Black, Brown, Bruised: How Racialized STEM Education Stifles Innovation*. Harvard Education Press.

Recommendation 4.6: Track Data That Matters

The quality of a university's undergraduate engineering program can be measured in many ways. However many rankings are based on academic measures that do not reward better outcomes for marginalized, low-income, and underrepresented groups. Current rankings drive universities to focus obsessively on what schools scored above them are spending, and whom they are accepting, instead of what students learn.[155] This creates an environment where access is viewed as a negative. A low acceptance rates is viewed as a positive, which further limits access. It is comparatively less challenging for engineering programs to retain and graduate students who are the most academically prepared and from families whose income is in the highest quartile. It is much more challenging to retain and graduate students from the lowest-income quartiles, marginalized students, and those from underrepresented groups. Our current measures and program rankings reveal what we truly value; and what we value is not aligned with creating better access, being student-centered, and severely limits our ability to diversify. Stated another way; you are what you measure.

ASEE should begin to collect and publish from engineering and engineering technology programs information on the enrollment percentage and demographics of students in their programs and their outcomes disaggregated by race, ethnicity, gender, family income, and field of study. These metrics are similar to what is recommended in the NAE report Advancing Antiracism, Diversity, Equity, and Inclusion in STEMM Organizations.[156] This ranking system will reveal those programs that truly value access, diversity, and student success

It is recommended that the following data be measured for all undergraduate engineering and engineering technology programs:

- How many students complete an engineering degree.
- How many students switch to and complete a non-engineering degree.
- How many students leave engineering programs without a degree.

Other measures to consider include the following.

Student retention in engineering: This measures the percentage of students who continue their studies in engineering and do not drop out (for any reason). Measuring the percentage of retained students in engineering programs from year to year can be a good indicator of the effectiveness of the recommendations. It may involve tracking the number of students who complete an engineering program compared to the number and demographic characteristics of those initially enrolled, the student retention rate per academic engineering program, the number of students who switch majors or leave the institution, analyzing the reasons for dropouts, and creating interventions to address issues. Evaluation methods may include

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[155] Selingo, J.J. (2015). *College (un)bound : the future of higher education and what it means for students*. Las Vegas, Nv: Amazon Publishing.

[156] National Academies Of Sciences Engineeri, and, E., And, B., and, B., Board, Board and Stem, in (2023). *Advancing Antiracism, Diversity, Equity, and Inclusion in Stemm Organizations: Beyond Broadening Participation*. National Academies Press.

surveys, tracking retention data, and analyzing academic records. Retention rates should increase over time as the recommendations are implemented successfully.

Performance in fundamental courses: This measures how well students perform in fundamental courses where mathematics tools are essential for understanding the material. Monitoring may include metrics such as GPA, exam scores, and the number of students who complete the course. Evaluation methods may include analyzing academic records and conducting assessments before and after implementing the recommendations.

Underrepresented students: This measures the increase or decrease from year to year in students from underrepresented groups who enter and stay in engineering programs, with metrics such as enrollment data, retention rates, and graduation rates, compared to the overall student population. The reasons for the percentage change can be analyzed to create interventions to address identified challenges. This metric would help evaluate the impact of recommended changes on diversity and inclusion in engineering and whether they have improved access and success rates for underrepresented groups. Evaluation methods may involve conducting surveys and analyzing demographic data of students and graduates.

Student perception: This measures students' recognition of mathematics as a useful tool in solving engineering problems. Through surveys or focus groups, students' perceptions of the value of engineering problem-solving skills can be evaluated compared to the conventional requirement for mathematics proficiency. Pre- and post-recommendation surveys or focus groups and analysis of the results can provide insight into students' perceptions of and interest in engineering.

Workplace performance and success: This measures how well students perform in internships and full-time engineering-related jobs after graduation. Evaluating their success in the workplace as interns and full-time employees can be a valuable metric to determine whether students are appropriately prepared for their careers. Evaluation methods may involve tracking employment data and conducting surveys of interns and graduates as well as employers to assess the quality and preparedness of engineering interns and graduates. Metrics can include the number of students who obtain engineering-related internships or full-time employment, feedback from employers on interns' or recent graduates' performance, and the success rate of graduates in obtaining engineering jobs.

Competency of key topics: This measures the degree to which students are proficient in key concepts in engineering and mathematics-related subjects, with metrics such as course activity and exam scores, project evaluations, and the number of students who demonstrate proficiency. Evaluation methods may include conducting pre- and post-recommendation assessments and analyzing improvement trends.

FE exam scores: The standardized Fundamentals of Engineering (FE) exam assesses students' mastery of engineering fundamentals. Using FE exam scores as an independent measure can provide an objective means of evaluating the effectiveness of the recommended changes.

Metrics on FE exam scores can include comparing the average student scores of programs that adopt the recommendations before and after implementation, analyzing the pass rate of students on the FE exam, and tracking the number of students who take the exam. Evaluation may involve collecting data on the FE exam scores and conducting surveys of students who have taken the exam.

Conclusion

These metrics enable a comprehensive assessment of the effectiveness of the recommendations in transforming engineering education, improving student retention in engineering, increasing the number and diversity of students earning engineering degrees, and ensuring that each motivated student has a path to success in engineering.

To ensure a dynamic, competitive, and innovative workforce, engineering programs must develop the mindset and programs that will admit and support more students from marginalized groups. This report provides engineering programs with a curricular roadmap and teaching methods to improve educational outcomes for all students. The above measures are effective ways to determine both the access and excellence a of engineering and engineering technology programs.

CHAPTER 7. Leveraging Strategic Partnerships

Partnerships between engineering programs and numerous strategic partners, including employers, accreditors, professional societies, state and federal government, PK-16 educators, developers of education materials, and higher education IT system providers are essential to the engineering education ecosystem. Program changes to meet future needs must engage all partners to help envision and design appropriate innovations. Some recommended actions include fostering broad collaborations to assist K-12 educators and counselors in understanding engineering practices better and deepening community pathways to engineering opportunities; expanding institutional collaborations with industry, professional societies, and government to better align curricula with needed competencies and skills development in ways that integrate the societal context of engineering into coursework; and continuing collaborations with accreditation organizations, licensing bodies, and governmental agencies to align systems supporting the success of the transformed engineering curriculum.

Broadening Collaborations with PK-12 Educators and Advisors to Facilitate Pathways into Engineering

Over several decades, many institutions (academia, industry, and professional societies) have contributed to K-12 student outreach, but many of these efforts depend on singular connections and efforts. Although they have furthered student interest in engineering, they have not led to substantial impacts on the broad system of PK-12 education or the diversity of students in undergraduate engineering programs nationwide. Higher education is highly dependent on the quality of the outcomes of the PK-12 school system in preparing students. There are many excellent PK-12 schools and school experiences in the United States, but there are also many that are not adequately preparing students for higher education. In addition, most PK-12 schools do not have a curriculum that includes engineering. Active engagement with PK-12 education will be foundational to an improved and diverse engineering education.

By expanding the knowledge base and improving the self-efficacy of PK-12 teachers, especially in-service teachers with no experience teaching engineering and engineering technology, all students will benefit from a greater understanding of engineering practices and help to foster engineering critical thinking skills. By improving the understanding of the practices and breadth of engineering and potential jobs with PK-12 teachers, counselors, students, and parents, a more diverse population of PK-12 students will learn about engineering opportunities and gain self-confidence in pursuing STEM, which will hopefully lead to greater diverse interest in pursuing engineering pathways in higher education.

Individuals interact with the engineered world daily, but there remains a lack of education about how this world operates, how it is created, and how professions are involved. Although evidence of engineering is pervasive, educational experiences dedicated to comprehending how engineering develops and assesses technological solutions are notably insufficient compared to adjacent STEM areas. Many engineering learning experiences in schools are often treated as “add-ons” to regular activities, services to other disciplines, or elective courses in career pathways. For all these reasons, the case for explicitly including engineering in PK-12 education is compelling.

But engineering has historically been an exclusive area of both study and professional practice. Regrettably, many of the nation’s youth lack intentional exposure to the concepts and practices necessary for engineering literacy during their typical school day. Evidence also indicates that low-income and underserved minoritized youth experience the least exposure to engineering coursework and score significantly lower on a national exam measuring technology and engineering literacy.[157] Increasing opportunities for all students to engage in engineering learning can be a crucial step toward diversifying the workforce and advancing US technological and innovative output. The following recommendations aim to help set the stage for an inclusive engineering mindset through systemic change in PK-12 engineering learning.

A commitment to equitable engineering education access early in children’s education is necessary to dismantle barriers to engineering career pathways, instill a sense of belonging in the field, and provide the foundational learning experiences essential for student success across diverse engineering-related career trajectories.

By expanding the knowledge base and improving the self-efficacy of PK-12 teachers, especially in-service teachers with no experience teaching engineering and engineering technology, all students will benefit from a greater understanding of engineering and its practices, which will help foster engineering critical thinking skills. By improving the understanding of the practices and breadth of engineering and potential jobs with PK-12 teachers, counselors, students, and parents, a more diverse population of PK-12 students will learn about engineering opportunities and gain self-confidence in pursuing STEM, which will hopefully lead to greater diverse interest in pursuing engineering pathways in higher education. It will expand who enrolls in engineering programs but may also impact what kinds of engineering they pursue in communities they care about. It will also help support students in community-oriented ways in their engineering pathways.

Collaborations with Industry, Professional Societies, and Government

Expanding university and college collaboration with industry, professional societies, and government will result in better alignment of the curricula with needed competencies and skills development and integrate the societal context of engineering into the substance of the engineering curricula.

[157] U.S. Department of Education. Institute of Education Sciences, National Center for Education Statistics, National Assessment of Educational Progress (NAEP), 2018 Technology and Engineering Literacy Assessment.

Many programs involve engineering professionals and organizations as guest speakers, sponsors of capstone projects, and extracurricular activities, such as plant tours or student society hosts. These experiences are usually motivating and appreciated by the students, but they are often sporadic and dependent on informal connections.

Organizations such as regional university accreditors, ABET, and NSPE do not operate in a vacuum. Academic organizations and professional societies contribute volunteers to these accreditation and licensure organizations to establish criteria, qualifications, evaluation, and testing standards. When new ideas are suggested, these volunteers consider how they can help the professions, whether and how they can be implemented, and, if appropriate, when they can be imposed.

ABET criteria are changed through a well-defined process that involves input from various stakeholders, including educators, industry professionals, and accrediting bodies. Here is a general outline of how ABET criteria changes typically occur:

1. *Needs assessment:* ABET reviews its criteria and assesses whether they adequately reflect the evolving needs of engineering education, industry, and society. If there is a consensus that changes are needed to better align with current trends and demands, the process moves forward. Suggestions for changes can come from colleges, industry, professional societies, and ABET councils or commissions.
2. *Task force formation:* ABET forms a task force with experts from academia, industry, and related fields to review the existing criteria, identify gaps, and propose changes to address those gaps.
3. *Drafting and proposal:* The task force drafts new or revised criteria incorporating the proposed changes. This proposal outlines the suggested modifications, with the rationale behind them and the expected benefits.
4. *Public input:* The draft proposal is often made available for public comment and feedback. This step allows educators, industry professionals, students, and other stakeholders to provide input, voice concerns, and suggest refinements.
5. *Revision and review:* Based on the feedback, the task force revises the proposal as needed, seeking to strike a balance between the different viewpoints and recommendations while maintaining the integrity of the criteria.
6. *Approval:* The revised criteria proposal is submitted to the appropriate ABET governing body for review and approval. This governing body evaluates the proposal's alignment with ABET's mission and objectives as well as its potential impact on engineering education.
7. *Implementation:* Once approved, the updated criteria are communicated to accredited programs and institutions, which are given time to adapt their curricula, assessment methods, and processes to align with the new criteria.
8. *Transition period:* ABET often provides a transition period for programs to meet the requirements of either the old or the new criteria. This allows institutions to make necessary adjustments without disrupting ongoing educational activities.

9. *Assessment and feedback:* After the new criteria have been in place for a while, ABET gathers feedback from accredited programs, assesses their effectiveness, and makes further refinements if necessary.

This process may vary slightly based on the specific changes considered and the governance structure of ABET. Working with ABET will be critical in the process to change undergraduate engineering and engineering technology education as recommended in this report.

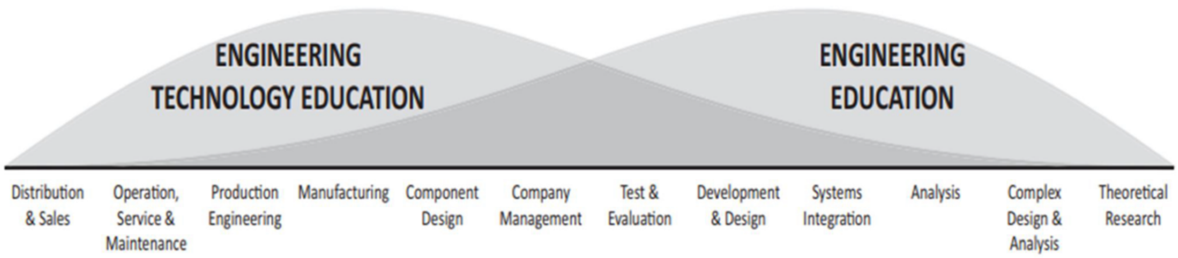
The Artificial Divide Between Engineering and Engineering Technology

"What has been largely absent from most discussions of the future of the US technical workforce is the role that engineering technology (ET) education—both two- and four-year degree pathways—plays or should play in supporting the nation's capacity for innovation."[158]

There is a continuum in technology that moves from vocationally trained skilled tradespeople at one end to technicians narrowly focused on one aspect of technology, to baccalaureate engineering technology graduates (BS ET graduates), and to the BS engineering graduate who have mastered whole technological systems. There is a clear distinction between a *technician* and a *BS ET graduate*. ***The BS ET graduate is an applied engineer who works collaboratively with other engineers, technicians, and skilled tradespeople. BS ET graduates serve an important and unique role as the "integrators" in business and industry.*** BS ET graduates have a deep understanding of the human-made world and use a problem-solving methodology that can lead to innovation by developing new and improved artifacts, systems, and processes. Engineering technology programs are more diverse in serving students of color when compared with engineering programs.[159] The figure below shows the similarities, differences, and overlaps between a BS engineering graduate and a BS engineering technology graduate. As shown in the figure, these fields have differences in the extremes and much overlap across the range.

[158] *Engineering Technology Education in the United States: Summary* (2017) *NAE Website*. Available at: https://www.nae.edu/173075/Engineering-Technology-Education-in-the-United-States-Summary (Accessed: 18 March 2024).

[159] Irwin, J.L. *et al.* (2023) *DEIB in engineering technology programs in the US*, *ASEE PEER Document Repository*. Available at: https://peer.asee.org/deib-in-engineering-technology-programs-in-the-us (Accessed: 18 March 2024).



Source: *Engineering Technology Education in the United States*, (2017) National Academy of Engineering

Figure 3 Similarities, differences, and overlaps between engineering and engineering technology

Engineering is both a body of knowledge and a process. The engineering process has differing levels of sophistication, implying that the higher education of those engaged in the engineering process is prepared at different levels. These levels could be defined as a continuum that span the most applied to the most theoretical levels of education and learning of the engineering process. Another continuum would span the design/build and maintain/sustain engineering processes or artifacts of engineering. We need a higher education system that prepares graduates for the differing levels of sophistication of the engineering process and stops looking at engineering in higher education as a very narrow discipline with a single path of entry.

The bifurcation between engineering and engineering technology manifests itself in two additional critical areas. It is generally more difficult for BS engineering technology graduates to sit for PE licensure exams to become licensed engineers. The US Office of Personnel Management (OPM) doe not recognize BS engineering technology graduates as entry level engineers unless they have one year of engineering experience, which severely limits new graduates opportunities to hold positions classified as engineers in the government. Work need to be done with the National Council of Examiners for Engineering and Surveying (NCEES) to create an equitable pathway to Professional Engineering licensure for BS engineering technology graduates.

Professional engineers are responsible for protecting the health, safety and welfare of the public. The ASEE board unanimously adopted a position statement that emphasizes that both ABET accredited BS engineering and BS ET graduates should be treated equitably regarding professional licensure and both are fully capable of protecting the heath, safety and welfare of the public.

Work also needs to be done with the US Office of Personnel Management (OPM) to change job classifications that would allow BS engineering technology graduates to hold positions currently classified as engineers.

Additional issues involve CIP codes and SOC codes. CIP codes lump together graduates of 2-year technician programs with graduates of 4-year engineering technology degrees. SOC codes do not acknowledge that baccalaureate engineering graduates commonly enter the workforce as engineers. Combined, these twin issues result in artificially deflated salaries for baccalaureate ET graduates and negative advertising and perceptions of the value and contributions of engineering technology graduates.. Work needs to be done with US Department of Labor and the US Department of Education to correct and update the CIP and SOC codes.

ABET Differentiation of Engineering and Engineering Technology

ABET's consistent replacement of 'engineering' with 'engineering technology' in the criteria primarily reflects the academically imposed distinction following the 1955 Grinter report. Engineering faculty at that time were unwilling to adopt the suggested bifurcation of the curriculum into an 'analytical/research' path and an 'applied' path. From that point forward, the academic community has enforced this semantic distinction. Engineering schools did not want the developing Engineering Technology programs to be called 'engineering' programs, leading to the current situation of having two different accreditation commissions within ABET (EAC & ETAC).

A more practical way to look at the distinction, which most agree with, is that the two terms represent the central difference in the focus of the two approaches to engineering activities. Engineering programs emphasize, to a greater degree, the analytical and theoretical aspects of the engineering/science/technical topics that are part of the curriculum but give less emphasis to the application of state-of-the-art technology to current issues/problems/opportunities. Conversely, engineering technology programs emphasized to a greater degree how existing technical/engineering/science knowledge and tools can be applied to deal with current technical issues/problems/opportunities. Both programs turn out students who are engineers. Functionally, there is a dual pathway to becoming an engineer – either through an ABET accredited baccalaureate degree in engineering or engineering technology.

How does this difference show up in the curricula? -- primarily in the amount of time students in the programs spend in laboratory-based classes. In general, if you look at comparable curricula (EE vs. EET or ME vs. MET), you will see that, from a topical perspective, both programs cover very much the same topics. What will be different, though, is how much of the study of those topics also includes lab activity. The engineering technology programs generally have 2 - 3 times more lab work than the engineering curriculum. The emphasis of the labs, and a central tenet of ET programs, is that labs, particularly lab equipment, must be maintained at state-of-the-art levels so that graduates are well-versed in the extant tools of their chosen field upon graduation. The countering effect in the coverage of topics in the ET curriculum focuses on classroom studies on applications of existing technology to real-world situations and less emphasis on detailed analytical modeling or high-level design concepts.

Design activities are generally done at the system level rather than at the detailed component level, and device modeling typically relies on accepted, general-purpose models of components and devices. Engineering programs, on the other hand, will give more attention to fundamental design activities (designing the next low-noise switching power supply as opposed to choosing a suitable switching power supply to operate a device), application of advanced mathematical techniques to modeling of devices, and systems (finite element modeling of the stresses on a bolt thread to determine failure points as opposed to using standard models of bolt strength) are two examples of the differences between the ET and the E curricula.

Community College's Partnership Role

Community colleges have to be strategic partners in transforming engineering education to better serve the needs of our nation. The traditionally smaller classes at community colleges, especially in critical developmental and foundational courses in the engineering curriculum, are well suited for a welcoming and student-centered approach, a critical transformational approach that is being advocated in this document. Community colleges have always been a suitable alternative for those individuals seeking higher education who may not be ready to attend a four-year institution. Community colleges play a significant role in collaborating with industry to provide the workforce development needed to meet their needs. As we look at the challenges that face us as we change engineering education, the nation's community colleges can play an important part and, therefore, need to be included in the solution.

Community colleges have long been a workhorse of the nation's economy and higher education system, offering developmental skill courses, career technical education (CTE), transfer preparation, and 2-year associate degrees to build a skilled workforce.[160,161] They are a vital component of the nation's postsecondary education system, serving 6.2 million credit students or roughly 36% of all higher-education undergraduate students.[162]

Current Challenges for Community Colleges

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160 American Association of Community Colleges. (2012). Reclaiming the American dream: 21st-Century Commission on the Future of Community Colleges. Retrieved from https://eric.ed.gov/?id=ED535906

161 Cohen, A. M., Brawer, F. B., & Kisker, C. B. (2014). The American community college. In A. M. Cohen, F. B. Brawer, & C. B. Kisker, *The American community college.* San Francisco: John Wiley.

162 Ginder, S. A., Kelly-Reid, J. E., & Mann, F. B. (2017). *Enrollment and employees in postsecondary institutions, fall 2016;.* Washington, D.C.: National Center for Education Statistics. Retrieved from http://nces.ed.gov/pubsearch

1. While community colleges may serve roughly 36% of all undergraduate students in higher education, only one out of four community college degree seekers will still complete their program of study.[163]
2. Keeping the students engaged as they navigate the developmental courses that they may need in order to enter a STEM-related degree program.
3. Working with students who are not math or science-ready for engineering degrees.
4. Limited financial resources constrain the ability to offer all of the courses needed in the first two years for students interested in many engineering specializations.
5. Seamless transfer from an engineering science or engineering technology program at the community college to a four-year program.
6. A challenge for student engagement at the community college level is that students often have multiple off-campus responsibilities that limit their time for engagement in the college experience.[164,165,166,167]

Opportunities for Community Colleges

Community colleges provide graduates who are ready to continue their education at a 4-year level. In the STEM areas, community college graduates can make up for those students at the 4-year level who have failed to continue on into the upper years. These students typically graduate with less debt[168] than their four-year counterparts and more than likely will be considered as graduates of the four-year program, with their time spent at the community college only serving as a line item on their resume.

In many situations, especially those in high-demand careers, community college graduates may have access to employer funding to continue their education at the 4-year level. Four-year colleges are typically not equipped to easily transition the high school graduate who is not math/science college-ready into their engineering or engineering technology program. Community colleges can provide the developmental courses needed for under-prepared students to complete the necessary foundation courses so that they can successfully transfer into an engineering-related degree program.

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[163] Schneider, M., & Yin, L. M. (2012). *Completion matters: The high cost of low community college graduation rates.* Retrieved from aei.org: http://www.aei.org/files/2012/04/02/-completionmatters-matters-the-high-cost-of-low-community-college-graduation-rates_1734075773640.pdf

[164] Hammer, L. B., Grigsby, T. D., & Woods, S. (1998). The conflicting demands of work, family,. *The Journal of Psychology*, 132, 220-226.

[165] Hanson, T. L., Drumheller, K., Mallard, J., McKee, C., & Schlegel, P. (2011). Cell phones, text messaging, and Facebook: Competing time demands of today's college students. *College Teaching*, 23-30.

[166] Hirschy, A. S., Bremer, C. D., & Castellano, M. (2011). Career and technical education (CTE) student success in community colleges: A conceptual model. *Community College Review*, 296-318.

[167] Lester, J., Leonard, J. B., & Mathias, D. (2013). Transfer student engagement blurring of social and academic engagemen. *Community College Review*, 202-222.

[168] Gonzalez Canche, M. S. (2020, November). Community College Students Who Attained a 4-Year Degree Accrued Lower Student Loan Debt than 4-Year Entrants Over 2 Decades: Is a 10 Percent Debt Accumulation Reduction Worth the Added "Risk"? If So, for Whom? *Research in Higher Education*, pp. 871-915.

Most classes at community colleges have a low student-to-faculty ratio, and as Tinto[169,170] has pointed out in his research, student engagement is a key component in student retention. Many graduates of community colleges report that time management is a valuable skill they have learned while attending college. This skill was developed not in a class they took, but rather through the fact that many community college students need to balance work and school simultaneously, and in some cases, attending college while working full-time. Those graduates who continue their education at the four-year level will find themselves well-prepared for completing their education.

Not everyone is ready to earn a bachelor's degree, but studies have shown that those with a college degree, even an associate's degree, will make more money over their lifetime than those individuals without a degree. Students need multiple pathways to achieve a degree, and in the case of those who will never earn a bachelor's degree, there needs to be an opportunity to transfer their credits to another institution and earn a degree. Someone failing to complete a 4-year engineering science degree can still have a very successful career with an associates in engineering technology.

If we are looking to reverse a trend in which Hispanic, Black, American Indian, and Alaska Native people make up 37% of Americans aged 18 to 34, but only 26% of them successfully complete a bachelor's degree in STEM, with even fewer graduating in engineering. Changing this statistic will require assistance from all sectors and community colleges can certainly make a difference. Community colleges, which enroll close to 50 ethnically underrepresented college students, including African Americans, Latinos, American Indians, and Southeast Asians, are of particular importance when examining faculty–student interaction for underrepresented students of color.[171] Community colleges stand at a unique position along the educational pipeline and often serve as points of access and entry to continued higher education for underrepresented groups. Engagement outside of the classroom has been shown to benefit those from underrepresented groups than their white peers.[172]

Recommendations: Leveraging Strategic Partnerships

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169 Tinto, V. (1997). Classrooms as communities: Exploring the educational character of student persistence. Journal of Higher Education, 68, 599-623. doi:10.1080/00221546.1997.1177 9003

170 Lancaster, J. R., & Lundberg, C. A. (2019, April). The Influence of Classroom Engagement on Community College Student Learning: A Quantitative Analysis of Effective Faculty Practices. *Community College Review, 47*(2), 136-158.

171 Cohen, A. M., & Brawer, F. B. (2002). *The American Community College.* San Francisco: Jossey-Bass.

172 Chang, J. C. (2005, November). Faculty-Student Interaction at the Community College: A Focus on Students of Color. *Reseach in Higher Education, 46*(7), 769-802.

Recommendation 5.1: Integrate experiential learning for all students in a societal and professional context at the program level.

Ideally, this should happen at least once at the lower levels of the curriculum and once at the upper level, at four-year and community colleges should be included. To accomplish this, a shared site (repository) with modules created by professional societies and government and industry organizations should present and host topics and challenges. The impact of this recommendation will be that students will be more interested and motivated to understand the engineering sciences as they are used in realistic designs, and they will begin to consider the societal impact of these designs.

Recommendation 5.2: Foster partnerships among accreditation agencies, academia, and industry councils that focus on engineering in a societal context.

This new council should explicitly include some professionals from non-engineering-related fields.It's goals should be to monitor societal and professional needs to ensure that engineers understand that they are ethically bound to serve the public good. In this mode, they can generate and engage in the first three steps above in criteria change.

For example, ABET Student Outcome 4 is "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts." Student training could include social injustice examples such as highways that split communities, digital deserts, pesticide distribution practices, underserved health communities, structural barriers, or noise pollution.

Recommendation 5.3: Facilitate discussion among ABET, NSPE, and academic institutions regarding the divide between engineering and engineering technology.

Because of the challenges created by the current two silo systems between engineering and engineering technology, some students and engineers have faced challenges in transferring between programs and in licensure and professional job restrictions. To address this divide, we suggest a different approach and recommend, at a minimum, a third option that distinguishes BS degree programs in engineering technology. We also believe there is an opportunity to consider more competency-based silos for degrees and licensure.

For example, BS programs in engineering and engineering technology are held to not only general criteria for either engineering or engineering technology by ABET, but in addition, if they have an adjective such as electrical, mechanical, or robotics, then ABET will work with the program to determine which specific degree program criteria should also be applied. However, sometimes the difference in curricular experience between engineering and engineering technology programs is relatively small, and employers hire people from either type of program for certain jobs, often labeling the job positions as engineering positions. Thus, much like referenced in the Grinter report, engineering professionals sometimes demand very theoretical and design skills, and other times call for very transformative and applied skills. ABET should ensure that it does not add to the 'siloing' effect on students by forcing commission choices (engineering or engineering technology) or specific program choices (electrical, mechanical,…)

especially because engineers of the future are going to need to work in ever more integrated and convergent environments.

Currently, the perceptions of the prestige and opportunities between degrees labeled engineering versus engineering technology, as well as the perceived need to only count coursework labeled as engineering or technology are problematic. That is, even courses that cover the same topics for a significant proportion of the course can only count in one or the other degree plan, forces barriers to degree completion that may be irrelevant to employers.

Recommendation 5.4: Create a new accreditation option specifically for BS degree programs in engineering technology or modify EAC to include BS engineering technology programs.

BS Engineering Technology programs serve an essential and unrecognized role in preparing engineers. The best BS engineering technology programs are more similar to traditional engineering programs than they are to AS technology programs that prepare technicians. The unrecognized contributions of BS engineering technology programs in preparing engineers can be partially remedied if ABET were to modify the existing Engineering Technology Accreditation Commission (ETAC) requirements to include onlyBS engineering technology programs and not technicians. A new ABET accreditation option needs to be created for engineering technicians that would take existing elements of the current ETAC program to evaluate and accredit associate degree and BS programs that do not meet the enhanced standards for BS engineering technology programs.

Another option is to have the Engineering Accreditation Commission (EAC) change/reduce the (outdated) one year of math and science. Current EAC student outcomes are heavily focused on “design”, while the ETAC student outcomes stress “application”. That language could be modified, and please both. With these small changes, engineering technology graduates could fit under EAC, and the licensure and US Ofice of Personnel Management OPM issues described earlier disappear.

Recommendation 5.5: Form strategic partnerships with community colleges to bring about change, especially regarding credit transfer.

These partnerships will allow for a more inclusive environment, one in which more individuals can be given an opportunity to succeed. A welcoming and student-centered environment, one in which the student is engaged in their education, has been shown to be a successful model, not only at the baccalaureate level but has also been successful at the community college with promising results.[173]

Community colleges are already playing a strategic role in programs like Minnesota State University’s Iron Range Program or in four year engineering technology programs that rely on students feeding the upper two years from their partner community colleges. Community

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[173] McCormick, A. C., & McClenney, K. (2012). Will these trees ever bear fruit? A response to the special issue on student engagement. *The Review of Higher Education*, 307-333.

colleges are also well positioned to work with high schools as they develop Career Technology Education (CTE) pathways or provide alternative pathways for seniors, and in some cases, in their junior year to take college-level courses.

Recommendation 5.6: Foster broad collaborations to assist PK-12 educational systems to value and champion engineering learning.

This recommendation will foster and enhance PK-12 collaboration to improve understanding of engineering practices and deepen pathways to engineering opportunities. It also highlights the importance of community in students' futures in engineering. It focuses on making engineering more accessible to students through school and community connections and reframes who can successfully pursue engineering.

The uneven integration of engineering in PK-12 schools limits the ability of the discipline to achieve the goals outlined in this report. Recognizing engineering as a defined discipline with distinct career connections that can be learned and refined over time is crucial. While engineering design activities can be used as a vehicle for integrated STEM instruction or teaching other disciplinary content in engaging ways, engineering as a discipline is much more. It extends beyond the practice of design to encompass concepts and practices that can be taught with increasing sophistication throughout students' educational journey. Given the current landscape of engineering in PK-12, it is imperative to be specific about the identity of the engineering discipline in a manner that steers clear of the polysemy and overshadowing broadness of the STEM acronym (STEM education practices may clash with the purpose and intent of engineering as a distinct discipline and professional area of practice in PK-12). In doing so, PK-12 engineering learning can be aligned to engineering as a unique discipline, with continual evaluation of whether engineering-related instructional activities are accurately depicted to children in a manner authentic to engineering-related professions.

The *Framework for P-12 Engineering Learning*[174] provides a vision for a defined and cohesive educational foundation to support this recommendation. The framework defines engineering in PK-12 as a discipline with specific objectives that include (a) cultivating engineering literacy for all students, (b) enhancing the academic and technical achievement of students through the integration of concepts/practices across school subjects, (c) providing insights into engineering-related career pathways, and (d) developing a foundation for students who matriculate to a postsecondary program for an engineering-related career. These objectives can be scaffolded across learning experiences to move from general engineering literacy for all to preparing students for undergraduate engineering and engineering technology programs (table 1). The scientific revolution created a need for PK-12 students to learn chemistry, physics, mathematics, and biology and the scientific discovery process. The technological revolution, building on math and science, requires PK-12 education to include engineering and computer

[174] Advancing Excellence in P-12 Engineering Education & American Society of Engineering Education (2020). *A Framework for P-12 Engineering Learning: A defined and cohesive educational foundation for P-12 engineering.* American Society of Engineering Education. https://doi.org/10.18260/1-100-1153-1.

science and the engineering design process, which are the foundational elements of a technological world.

Outreach and collaboration nationwide with PK-12 educators and advisors can broadly influence student understanding, interest in, and preparation for engineering and build broader community pathways into engineering. This is particularly important for socioeconomically disadvantaged school districts in rural and urban settings, where resources limit the schools' capabilities. With engineering practices as part of PK-12 science standards in most states, we are provided a great opportunity to collaborate regionally and nationally to assist PK-12 teachers and counselors in increasing their capacity to fulfill these new requirements and address regional inequities among the schools. By fostering or enhancing broader collaborations between Colleges of Engineering/Engineering Technology, Colleges of Education (teacher preparation), and local PK-12 schools, a larger educational community can be developed to provide best practices, curricula, information, and more, for sharing in all PK-12 schools. If a common language and better understanding of the broad range of engineering majors and potential jobs is shared with those involved in PK-12 education, including teachers (in-service and pre-service), counselors, students, and parents, a more diverse population of students may become interested in studying engineering at the community college or university level.

The impact is an expected increase in PK-12 student interest in engineering, increased knowledge of careers, and preparation of high school graduates to matriculate to engineering programs. This recommendation also benefits all students and broader society as students develop STEM and engineering literacy and critical thinking skills in their PK-12 education.

A few examples of how universities and engineering programs can work with PK-12 schools include:

High School Courses for Articulated Credits

Postsecondary programs can be strengthened by improving and expanding articulated credits through high school programs. Articulated credits are granted to students for finishing high school coursework should they continue on to that partnering institution.

Dual Enrollment

In regions with challenges in high school staffing or equitable access, students' dual enrollment in both high school and college courses can yield a number of benefits for both the students and the high school. The arrangement, especially with classes at the partnering institution of higher learning, affords the students college credit before graduation and exposure to equipment and classrooms of a higher caliber and reduces the local school system's staffing and equipment costs.

Industry-Driven, Degree-Issuing Programs

The Pathways to Technology Early College High School (P-TECH) is another option for student exposure to rigorous engineering. Students graduate from high school with their diplomas and an associate's degree in engineering. While this option is most often for students entering the engineering profession, it is also a tool for equity to provide engineering mindsets and career trajectories for students who are typically underrepresented in the field.

Youth Apprenticeship Models

Youth apprenticeships, a type of WBL experience, are more structured opportunities for students to work with a local employer. The intended outcome is entry into the workforce. Local employers work with their school system and their Department of Labor to create a partnership for recruitment and training for high school students. Youth apprenticeship programs are a valuable resource for closing workforce gaps and exposing students to career pathways and engineering literacy.

Build Teacher Capacity for PK-12 Engineering

Among the many challenges to the expansion of PK-12 engineering learning is the lack of a prepared, motivated, and supported teacher workforce.[175] Teacher preparation and professional learning vary across the country for nearly every school content area, and engineering is no exception. Engineering may be taught by traditionally trained elementary, science, math, technology, and computer science teachers, or, as noted earlier in this section, career and technical educators. Colleges of Engineering that have engineering education departments can work with Colleges of Education in preparing more teachers to teach PK-12 engineering.

Partnering with Local School Districts

Engineering programs should consider partnering with local school districts and charter schools to assist them in implementing the *Framework for P-12 Engineering Learning.*[169] This would accelerate the infusion of engineering content into PK-12 curricula leading to better outcomes and interest in children wanting to pursue engineering as a profession. An example of a university partnering with a charter school is the Purdue Polytechnic High School, a joint collaboration between a university and a charter school offering a STEM-based curriculum and engineering literacy.

[175] National Academies of Sciences, Engineering, & Medicine (2020). Building capacity for teaching engineering in K-12 education.Washington, DC: The National Academies Press. https://doi.org/10.17226/25612

CHAPTER 8. Engineering a New Mindset for Engineering Education

Underlying this report's recommendations is the need to recognize that individual faculty members have their own mindset that may or may not serve the best interests of the diversity of engineering students. Faculty with fixed mindsets are at odds with the needs of students and the engineering profession. To best serve the requirements of society in the preparation of engineers, historical strengths need to be identified while attitudes and behaviors that limit engineering educators' ability to serve underserved populations need to be changed. The mindset of engineers is developed, not born, and it is essential that engineering educators and the curricula support all students' development of a growth mindset.

Mindset Recommendations

We propose that important changes are necessary for adopting a growth, inclusive, and asset-based mindset. The following recommendations are overarching and foundational elements when developing the curricula changes in this report.

1. Prizing behaviors where students self-initiate and self-regulate their own learning by faculty helping all students understand why they are asked to learn certain things and how they can deepen their own understanding. This leads to their becoming life-long learners, an essential attribute for this and future generations of engineers.
2. Prizing behaviors where students not only understand how to reduce systems to subsystems to find important patterns but also understand the value of emergent outcomes in complex systems that will be missed or destroyed in reducing a system to subsystems.
3. Prizing fields other than engineering that have valuable mindsets for aspects of systems in which engineers are less versed, such as business, public health, sociology, psychology, history, and others, and developing the mindset that modifying your own thinking to thinking that values trans-disciplinary thinking to address complex challenges.
4. Prizing the attitude that it is the engineering profession's responsibility, as much or maybe more than any field, to work to solve complex social problems that are constraining the overall health of our world, including climate change, racism, poverty, inequities, pandemics, misogyny, and xenophobia. First and foremost, if we are engineers and we claim to be those who can design complex systems for society, we must stop merely espousing our desire for diversity, equity, and inclusion and redesign ourselves to deliver the desired outcome, with all of its challenges, complexities, and conflicts.
5. Faculty embracing the growth mindset in their thinking and actions. Faculty need to flip from the mindset of "sage on the stage" to coaches and mentors of students. We must embrace the growth mindset in engineering education.

The following recommendations outline strategies for changing the perception of engineering, removing mathematics as an artificial barrier, transforming engineering education, and ensuring motivated students have a path to success.

Changing the Perception of Engineering

The perception that engineering is only for those with exceptional mathematics skills limits the number of people with an interest in studying engineering.[176] A study of data from 401 aerospace engineers and neurosurgeons examined the assertions "It's not rocket science" and "It's not brain surgery".[177] The study compared the result to a comparator group of over 250,000 participants in the UK population that completed the same cognitive test and concluded that "everyone has a range of skills; some people are better at some things and other people are better at other things, and it is very difficult to be better in everything across the board." Engineering involves problem-solving skills beyond conventional proficiencies in mathematics. These skills include creativity, critical thinking for solving real-world problems, and the ability to identify, analyze, and solve complex problems using a variety of techniques and tools, of which mathematics is an important but not the only one.

Recommendation 6.1: Change the perception of engineering by promoting the idea that engineering is for everyone who want to be a problem solver, not just those who excel in mathematics.

1. *Highlight and integrate into engineering curricula the diverse range of problems engineers solve:* Research has shown that the more students know about the range of problems engineers solve, the better their perception of engineering as not being only for those with higher self-perceived ability in mathematics.[178] The study found that students who were presented with examples of engineering problems in diverse fields such as health care, transportation, and infrastructure were more likely to perceive engineering as a field of choice that requires a variety of skills and knowledge.
2. *Embrace an asset-based mindset in the classroom*: Asset perspective is when students' cultural differences are seen as beneficial to the learning environment, as opposed to a deficit perspective, where cultural differences are perceived as detrimental to the learning environment.

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176 Daker, R. J., Gattas, S. U., Sokolowski, H. M., Green, A. E., & Lyons, I. M. (2021). First-year students' math anxiety predicts STEM avoidance and underperformance throughout university, independently of math ability. NPJ science of learning, 6(1), 17. https://doi.org/10.1038/s41539-021-00095-7

177 Usher, I., Hellyer, P., Lee, K. S., Leech, R., Hampshire, A., Alamri, A., Chari, A., & Brainbook (2021). "It's not rocket science" and "It's not brain surgery"-"It's a walk in the park": prospective comparative study. BMJ (Clinical research ed.), 375, e067883. https://doi.org/10.1136/bmj-2021-067883

178 Litzinger, T. A., Lattuca, L. R., Hadgraft, R. G., & Newstetter, W. C. (2011). Engineering education and the development of expertise. Journal of Engineering Education, 100(1), 123-150.

3. *Showcase through coursework the positive human impacts of engineering:* Humanistic engineering emphasizes the social impact of engineering design.[179] This means that engineering students are encouraged to think about how their work can benefit society and also to consider the ethical implications of their designs. By incorporating principles of humanistic engineering in engineering education and practice, it is possible to change the perception of engineering from a discipline solely focused on technical problem-solving to one focused on creating solutions that benefit society as a whole.

Removing Artificial Barriers

Mathematics is often perceived by students as abstract and disconnected from the real world and a barrier to entry into engineering. Recent research and initiatives on engineering education have shown that removing mathematics as an artificial barrier to engineering can increase student diversity and bring new perspectives and ideas into the discipline.[180] Engineering curriculum designed to incorporate real-world applications of mathematical concepts makes the subject more accessible and relevant to a broader range of students.

The inflexibility of the curricula is an artificial barrier that can be overcome. This can be achieved with *a design-by-choice flexible curriculum* that allows students to choose a career path through a program of study based on their individual interests, strengths, and career goals. This approach emphasizes student agency and autonomy, as well as the importance of interdisciplinary learning and the acquisition of practical, real-world skills.

Recommendation 6.2: Remove artificial barriers to the engineering profession through a design-by-choice flexible engineering curriculum.

The curriculum would prepare students by providing the tools and skills needed to adapt to new challenges and opportunities in a rapidly changing job market. Highlighting the broader skills and knowledge that engineers need to succeed in today's world. This would make engineering education more accessible, interdisciplinary, and relevant to students' interests, career goals, and real-world solutions. It would also promote lifelong learning by encouraging students to take ownership of their education and to develop the self-directed learning skills they will need to continue learning throughout their careers.

Key features of the flexible curriculum may include the following:

1. *Options and pathways to an engineering degree:* Many engineering disciplines involve the application of mathematical concepts from various areas, including calculus, linear

[179] M. L. Bolton, "Humanistic Engineering: Engineering for the People," in IEEE Technology and Society Magazine, vol. 41, no. 4, pp. 23-38, Dec. 2022, doi: 10.1109/MTS.2022.3219132.

[180] Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., van Baalen, S., Klaassen, R., & Boon, M. (2020). Interdisciplinary engineering education: A review of vision, teaching, and support. Global Journal of Engineering Education, 109(3), 508-555. https://doi.org/10.1002/jee.20347

algebra, and statistics. When students have the flexibility to choose courses, projects, and other learning opportunities, they can build their program of study in alignment with their interests and career goals.

2. *Real-world relevance in all engineering courses:* Curricular emphasis on practical, hands-on learning experiences helps students develop skills and knowledge that are directly relevant to their chosen career paths and make engineering feel more accessible and relevant.
3. *Interdisciplinary connections:* Courses and projects that are designed to connect across disciplines allow students to explore topics from multiple perspectives and integrate knowledge and skills from different fields, improving cognitive competence for solving complex engineering problems. A study of the intersectionality between engineering, competence, practice, and importance found that the most useful skill for students is the ability to coordinate multiple competencies in accomplishing a goal.[181]
4. *Encouragement of innovation and creativity:* A flexible curriculum that emphasizes the application of diverse skills and concepts to real-world challenges in creative and innovative ways can help students develop the critical thinking and problem-solving skills they need to tackle these challenges. Such innovation and creativity will benefit students throughout their careers.[182]
5. *Support for reflection and self-assessment:* The curriculum has built-in mechanisms for students to reflect on their learning experiences and assess their progress toward their goals, with support from faculty and advisors.
6. *Integrate Multiple Pathways Into and Within Engineering Education:* The engineering curriculum must become more flexible to allow multiple pathways into engineering as a career. This can be accomplished by creating more flexible ecosystems and pathways into and among engineering and engineering technology programs, community colleges, K-12, and emerging STEM professions. Examining traditional curricular barriers into engineering and within engineering will create a more flexible and welcoming environment. Working closely with K-12 schools and community colleges will provide more opportunities for students who currently do not show the interest or the aptitude to enter into engineering programs of study. Proactively building flexibility to create multiple pathways into and in engineering programs of study will result in more students pursuing engineering as a career and create a more inclusive and diverse engineering field.
7. *Transforming the Curricula and Pedagogy of Engineering Education:* To transform engineering education, shifting from a "survival of the fittest" mindset where only the most talented and hardworking students succeed to a growth or "gain the knowledge/skill" mindset is essential. This can be achieved by offering opportunities for mentorship, internships, and project-based learning, which allow students to develop

[181] Passow, H.J. and Passow, C.H. (2017), What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review. J. Eng. Educ., 106: 475-526. https://doi.org/10.1002/jee.20171

[182] Chang, T.-S., Wang, H.-C., Haynes, A. M., Song, M.-M., Lai, S.-Y., and Hsieh, S.-H. (2022). Enhancing student creativity through an interdisciplinary, project-oriented problem-based learning undergraduate curriculum. Thinking Skills Creat. 46, 101173. doi: 10.1016/j.tsc.2022.101173.

practical skills and gain real-world experience. Emphasizing the importance of continuous learning, growth, and skill development over just academic performance and providing opportunities for students to engage in interactive learning, such as real-world problem-solving exercises, can make engineering more interesting and enjoyable. Reframing the role of mathematics as a tool for solving engineering problems with interactive learning can also help students develop critical thinking and practical problem-solving skills and demonstrate the relevance of engineering to their career aspirations. This would help promote engineering as a career for problem solvers from all backgrounds and foster inclusivity in engineering education.

8. *Curriculum Reflecting Real-World Professional Engineering Activities and Ethics:* The engineering curriculum must better reflect the activities and skills required for professional engineering. This can be achieved by ensuring the curriculum includes a balance of theory and practical application, incorporating real-world engineering challenges and projects into coursework, and collaborating with industry partners to identify and incorporate relevant skills and knowledge. Aligned curriculum with professional engineering activities should better reflect the activities and skills required in the professional field. This can include incorporating more project-based learning, internships, and coop experiences, emphasizing teamwork and collaboration, and integrating real-world applications into coursework.

A curriculum with these features will make engineering education more accessible, interdisciplinary, and relevant to students' interests, career goals, and real-world solutions. It will promote lifelong learning by encouraging students to take ownership of their education and to develop self-directed learning skills to continue learning throughout their careers. And it will prepare students with the tools and skills needed to adapt to new challenges and opportunities in a rapidly changing job market.

Developing an Inclusive Mindset

Institutions and engineering programs can adopt a comprehensive approach to designing and delivering engineering education to ensure every motivated student has a path to success. This approach should address the barriers that may prevent some students from pursuing engineering degrees, such as financial constraints, inadequate academic preparation, inaccurate perceptions of engineering as a profession, and lack of support and resources.

In the next 50 years, the engineering profession, with its rapidly changing, complex, intertwined, and systemic challenges, will need even more engineers to have a growth mindset. We believe many existing aspects of engineering education already develop aspects of this mindset, in some ways better than other pre-professional education fields. Engineering students often face significant challenges and problems and have to overcome constraints and obstacles to find solutions. The complexity of challenges can reinforce the value of persistence in effort and the importance of taking feedback constructively. But we acknowledge that, for too many students, it feels more like they are being 'weeded out' because they are not smart enough to be here. We also acknowledge that engineers often come to believe that only the engineering mindset is valuable and do not adequately value the contributions and mindsets of other professions, especially those focused on the human situation and how people interact.

An inclusive mindset in the classroom can promote learning by creating a safe and supportive environment that values and respects diversity. Students who feel accepted and valued for who they are and their unique experiences are more likely to be engaged and motivated to learn. Inclusive classrooms prioritize equity and seek to eliminate any barriers to learning that students may face due to their background, culture, or identity. This can include providing materials and resources that reflect diverse perspectives, incorporating culturally relevant teaching strategies, and implementing differentiated instruction to meet the needs of all learners. Chapter 6 in this report includes recommendations that will lead to an inclusive mindset.

Inclusive classrooms also promote collaboration and encourage students to learn from each other's perspectives and experiences. This can help students develop critical thinking skills and expand their worldview beyond their own experiences.

Finally, an inclusive mindset can promote a growth mindset in students, encouraging them to embrace challenges, learn from mistakes, and persist in the face of obstacles. By fostering a positive learning environment that values diversity can help students develop the skills they need to succeed in school and beyond.

CHAPTER 9. Embracing the Challenge

We are living in extraordinary times as citizens of the US and the world. Digital transformation is affecting everyone and everything we do. Globalization is a disruptive force to our business, industry, and our societal structures, and climate change is an existential threat to humanity. In the U.S., racial inequities are finally being recognized by many, and we are beginning to seek solutions that will finally lead to a nation that practices the idea that all are created equal.
As engineers, we like to think our objectivity shields us from history, our culture, and current events, but this is not the case. Most of us grew up in this society that propagated the myths of our history. For at least 50 years, we have endeavored to diversify the engineering profession with marginal success.

Deficit-based efforts attempted to “fix” underrepresented groups so that they could fit into the white male culture of engineering. What was wrong with women and students of color that they didn’t all want to be engineers? Then we blamed the K-12 school system. Teachers weren’t doing enough; never mind that our school systems are still mostly segregated, with many of our underrepresented students attending significantly underfunded and underperforming schools. Then, we blamed advertising and messaging. We needed to change the image of what an engineer should look like. It's everyone's fault but our own. Yet still, women, African Americans, Native Americans, and Hispanics are significantly underrepresented in engineering.
But the cause of these issues runs much deeper.

We are all committed to preparing the best engineers of today and tomorrow. A significant catalyst is needed, however, to move the field beyond increasingly antiquated habits ingrained over the past 50 years. **The call to action of this report is to launch the development of a roadmap for creating an inclusive, flexible, humanized, and multipath engineering curriculum for all learners that prepares engineers with the growth mindset required for a successful and unseeable future as engineers.**

To transform engineering education, it is essential to shift from an exclusive “survival of the fittest” mentality to a growth or “gain the skill” mentality. This can be achieved by offering opportunities for mentorship, internships, and project-based learning, all of which enable students to develop practical skills and gain real-world experience. Emphasizing the importance of continuous learning, growth, and skill development, beyond academic performance, and providing opportunities for students to engage in interactive learning, such as real-world problem-solving exercises, can make engineering more interesting and enjoyable. Reframing the role of mathematics as a tool for solving engineering problems with interactive learning can also help students develop critical thinking and practical problem-solving skills and demonstrate the relevance of engineering to their career aspirations. All of these steps can help promote engineering as a career for problem solvers from all backgrounds and foster inclusivity in engineering education.

As engineering educators, it is vital that we examine **the root causes** of the challenges we face in creating the roadmap for an inclusive growth mindset. Research shows that we have designed a curriculum that is meant to keep people out. We force all of our students to take three semesters of calculus—even though the vast majority don't really need that. We have a rigid curricular structure, with long prerequisite chains and few free electives. We subject students to one- to two-years of academic hazing before they are allowed into "the club." We promote competition at all levels, even though social scientists tell us that competition does not motivate everyone. We design projects and exams that are so hard that many students fail, and we call it "character-building,"— and we justify it by claiming that everyone should experience failure of some sort as university students. We also use "rigor" as a means to continue to use our curriculum as a cudgel and keep people out. We say that we don't have a weed-out mentality, but we certainly perpetuate a weed-out system.

The pipeline analogy[183] has also harmed our ability to diversify engineering. A pipeline has only one entry point and one exit point. If you enrolled in the wrong math class in 7th grade, or if your high school did not offer advanced math courses, you cannot become an engineer. For most 7th graders, engineering is not in their thinking. Yet if they choose poorly, they are shut out of engineering unless they are willing to go back and enroll in remedial math courses to make up for their lack of foresight as 12-year-olds. This is not an attractive proposition for most.

What if we recognized and rewarded the tenacity of students who arrive in our engineering programs without the benefit of such foresight? What if the pipeline allowed for multiple entry points that accommodated differences in educational backgrounds and differences in the quality of K-12 education?

These are the types of questions we need to address. As engineers and problem solvers, we need to accept the challenges to create a more inclusive engineering profession and adopt a growth mindset. This report provides you with the reasons we need to make changes and the pathways to get there through specific recommendations. Are we up to the challenge?

Blueprint for Change

Change is never easy, especially at the scale proposed in this report. Transformational change can be accomplished through thoughtful use of successful change models and evaluating best practices. Incremental change over a short period of time will lead to transformational change. Organizational change, especially when involving large groups of people, often requires a systematic and pragmatic approach to ensure successful implementation.

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183 Pawley, Alice & Hoegh, J.. (2011). Exploding pipelines: Mythological metaphors structuring diversity-oriented engineering education research agendas. ASEE Annual Conference and Exposition, Conference Proceedings.

To address the challenges in making change and to recognize that simply writing a report and making recommendations without further guidance on how to follow up makes it difficult to get started and sustain the change of the magnitude as outlined in this report.

In January 2024, the second phase of this project started, where we began conducting the first of four “hybrid” convenings—online and at NAE headquarters in Washington, DC. These meetings will be to write *The Blueprint for Change* report that will include an implementation plan (tactical plan) for the recommended changes found in this report and recommendations for NSF to support the effort. The goal is to provide organizations with a comprehensive framework to manage change effectively, catering to the various mindsets and preferences of individuals within the organization.

Dissemination

The dissemination plan for the ASEE Mindset Report and the Blueprint for Change Report will begin in 2024. Dissemination will be through the ASEE Annual Conference, NAE channels, presentations by members of the author team, and publication of articles in relevant journals. If your academic program, professional society, industry or other interested party in engineering education would like to learn more or to schedule a presentation about this report and its recommendations, please contact Gary Bertoline at Purdue University bertoline@purdue.edu. Further information can also be found at the project website mindset.asee.org.

Glossary

Antiracism. Antiracism is defined as action and active engagement in support of dismantling supremacy or domination of one culture over another; the work of actively opposing racism by advocating for changes in political, economic, and social life.

Authentic. The term authentic implies that whatever is being discussed corresponds to observable facts and is grounded in reality and practice, rather than be in a more abstracted and less concrete space. In engineering education 'authentic' often means grounded in the actual practice of engineering. Because engineering is extraordinarily broad there are many, rather than a singular way, to be authentic.

Colorism. Discrimination and/or bias resulting from a process by which people of color, with more stereotypically ethnic features, especially dark skin but also dark hair, nappy hair, dark eyes, wide noses and lips, are disadvantaged relative to their less stereotypically ethnic, whiter looking, counterparts with lighter skin and hair, straight hair, light eyes, thinner lips and noses.

Decentering. Decentering actively focuses on equity and involves those from dominant groups, like White people (in the context of race) or men (in the context of gender), strategically distancing themselves (metaphorically or physically) from their proximity to power to allow for more just distribution of power, access, and opportunity.

Fundamental Attribution Error. The fundamental attribution error is a type of cognitive bias that leads people to overemphasize personality and underemphasize situational factors.

Intersectionality. Framework (and method and methodology) that emphasizes the idea that social categories and identity markers, such as gender, race, ethnicity, religion, ability, sexual orientation, and class, never operate independently of each other but jointly within the context of system or institutions that establish and reinforce **power** and privilege.

Privilege. Privilege, and particularly White privilege, refers to the unearned benefits that White people enjoy over non-White people, particularly if they are otherwise in the same educational, social, political, or economic circumstances.

Appendix

ASEE Mindset of the Future Methodology

In June 2020, the president of ASEE, Sheryl Sorby, challenged the profession to review the state of engineering and engineering technology education in preparing engineers. A 10-member steering committee was formed (see Frontmatter for a list of members) and asked to look at the current preparation of engineers versus what it can and could be if the curriculum were reenvisioned as if created in 2020 instead of 1955. The efforts build on the 1955 Grinter Report, which still has a significant influence on today's engineering curricula. The steering committee's charter was to take a fresh look at the preparation of engineers and ways to fundamentally improve the access, diversity, success and preparation of undergraduate engineering education students.

Findings of the Steering Committee

The Steering Committee sought to reimagine the engineering curriculum as though it were being crafted today instead of being based on the principles of the influential 1955 Grinter Report.

The steering committee met numerous times in 2020–21 to identify the main challenges for systemic engineering education curriculum changes. The members recognized the challenges facing the preparation of engineers and the daunting task required to systemically change the way engineers are prepared. They identified the following major themes and challenges:

- Increase diversity and inclusivity in engineering through curricular, pedagogical, and systemic changes.
- Evaluate first- and second-year engineering requirements to determine whether they meet current needs in the context of student success and attractiveness to women and other students from traditionally marginalized backgrounds.
- Adopt a growth mindset as a foundational element in engineering education.
- Evaluate the use of competition in project assignments.
- Create realistic, inspiring, and open-ended problems for students.
- Consider alternative admission requirements for engineering programs.
- Apply competency-based education and other high-impact educational practices in the preparation of engineers.
- Consider ways to make the engineering curriculum flexible, attractive, and welcoming to underserved and marginalized populations.
- Consider how to prepare engineering graduates for future jobs that do not exist today.
- Improve students' understanding of mathematics as a tool to solve problems.
- Evaluate the idea of having multiple paths to an engineering career.

The findings of the Steering Committee became the guiding principles for the formation of a task force. The 10-member Steering Committee developed a plan for engaging a larger Task Force to address the main challenges determined by the Steering Committee. This Task Force was charged with reimagining the undergraduate engineering curriculum as though it were being crafted today instead of being based on the principles and mindset taken by the influential 1955 Granter Report. The goal was to find ways to fundamentally improve undergraduate engineering students' access, diversity, success, and preparation.

Task Force and Working Groups

The steering committee engaged a larger task force to address the challenges listed above. The task force was charged with taking a fresh look at the preparation of engineers and ways to improve the access, diversity, success, and preparation of undergraduate engineering education students. The task force comprised engineering and engineering technology faculty, academic leaders, and industry representatives. They were charged with determining what engineering education changes should be considered across six areas, which were addressed by working groups of about 15 members, co-chaired by a steering committee member who was a faculty appointee serving on the working group. The lists of task force and working group members are in the Foreward. The working groups were:

Examine inequity issues and potential remedies

1. *Engineering Fundamentals and Values:* Develop a new canon for preparing engineers, to redefine fundamentals and values so that they are culturally relevant to students from traditionally marginalized backgrounds.
2. *Antiracism:* Address racial inequities and injustice in the preparation of engineers, with recommendations for eliminating it from the discipline through antiracism education and asset-based approaches.
3. *Inequities:* Address historical (well-known and lesser-known) inequities through measured accountability, climate, and equity recommendations.

Explore strengths and weaknesses of expanding students' growth mindset

4. *Learning Experience:* Develop recommendations for curricular and learning experiences that better integrate the cognitive, physical, and affective domains.
5. *Technical-Socio:* Develop recommendations to better balance engineering science/fundamentals and social skills, ethical reasoning, perseverance, ambiguity, creative thinking, and inter- and cross-cultural competencies.
6. *Pathways:* Develop recommendations for more flexible ecosystems and pathways into and among engineering, engineering technology, community colleges, K-12, and emerging STEM professions by examining traditional curricular barriers.

The working groups met virtually four times in February and March 2023 with the assistance of a skilled workshop facilitator from KnowInnovation, a group that designs and leads events to get people to engage in conversations that result in breakthroughs and innovation.

The goal of the workshops was to develop recommendations for creating an inclusive, flexible, humanized, and multipath engineering curriculum for all learners that prepares engineers with the growth mindset required for a successful and unseeable future as engineers.

The Curriculum Working Group

A seventh working group, the Curriculum Working Group, was established to consider the draft recommendations and reports from the other working groups in addressing the following charge:

> Recommend systemic changes to the engineering curricula to prepare graduates for a new way of thinking and doing and as future leaders addressing the needs of society for a rapidly developing globally connected technological world, [with] input from the six working groups to create the final Mindset Report. The Mindset Report [will include] recommendations to guide curriculum committees and provide case studies, practices, pathway flexibility, and value development practices to reach the desired outcome of an inclusive, flexible, humanized, and multipath engineering curriculum that prepares engineers with a mindset for the future.

The Curriculum Working Group met in Washington, DC, April 18–19, 2023, facilitated by KnowInnovation, and June 23–24. The members reviewed the six working groups' input and created the outline for the final report, with feedback from the task force. Ideas, thoughts, and comments were captured during the task force meetings and grouped into the six topical areas below.

Report outline developed by the Curriculum Working Group:

- Introduction & Cross-Cutting Themes
- Welcoming Environments
- Revise Curricular Barriers
- Research-based and Authentic Teaching (Pedagogy)
- Revise Institutional Structures for Student Success
- Strategic Partnerships

The Curriculum Working Group was subdivided into smaller writing teams to prepare the final report. This report will be used for the second phase of this project, which is to create a blueprint or roadmap for systemic change in engineering education. The NAE will also use this report as it plans work to produce an Engineer 2050 report.

The Curriculum Work Group had this charge:

<u>Develop the Mindset Report with recommendations for systemic changes to engineering curricula and pedagogy</u>

Curriculum Working Group - Recommend systemic changes to the engineering curricula to prepare graduates for a new way of thinking and doing and as future leaders addressing the needs of society for a rapidly developing globally connected technological world. The Curriculum Working Group took input from the six Working Groups to create the final Mindset Report. The Mindset Report includes recommendations to guide curriculum committees and provide case studies, practices, pathway flexibility, and value development practices to reach the desired outcome of an inclusive, flexible, humanized, and multipath engineering curriculum that prepares engineers with a mindset for the future.

While the six Working Groups functioned to generate draft proposals, the Curriculum Working Group served as the final arbiter, tasked with assimilating the findings and drafting the definitive "Mindset Report".

After gathering insights from all Working Groups, the Curriculum Working Group, meeting in Washington, DC, in mid-2023, devised an outline for the final report.

Mindset Report's tentative outline

- Introduction & Cross-Cutting Themes
- Welcoming Environments
- Revise Curricular Barriers
- Research-based and Authentic Teaching (Pedagogy)
- Revise Institutional Structures for Student Success
- Strategic Partnerships

The Curriculum Working Group further split into subgroups to handle different sections of the final report, culminating in the creation of the "The Engineering Mindset Report" document.

Vignettes

The following vignettes were submitted by Task Force members and others as examples of progressive programs in engineering education that align with many of the recommendations in this report..

Contents

Loyola University Chicago

Authors

Gail D. Baura, Ph. D. — *Founding Director & Chair, Professor,* *Engineering* *Program Co-Chair & Professor, Counseling Psychology*

Matthew J. Miller, Ph. D.

Loyola University Chicago's BS Engineering program began in Fall 2015. It has specializations of biomedical, computer, and environmental engineering, and an emphasis on systems. The program is structured to provide social justice for students and the faculty. All engineering courses are taught using mandatory active learning, specifically a modification of the U.S. Air Force Academy's minimal lecture style [1], in classrooms with no more than 24 students. During a 50-minute course meeting, the first 10 to 15 minutes are a mini-lecture, and the remainder of course time is devoted to collaborative or problem-based learning group activities. Each specialization is based on a social justice application, such as environmental engineering's application of water and wastewater treatment and management. Four social justice case study assignments, each with a different format, are embedded in four engineering courses, which teach the students to consider the effect of technology on society and to make ethical choices at work. Each faculty meeting begins with 15 minutes of student review, to ensure faculty members are aware of student support needs.

The faculty is diverse, with faculty composition modeling the diversity it wishes for its student population. Tenure-track (TT) Assistant Professors and non-tenure-track (NTT) Clinical Assistant Professors start at the same salary. Each new Clinical Assistant Professor has at least four years of industry experience, which is needed to teach each specialization's two-semester, industry-sponsored capstone course sequence. Faculty meetings were originally held twice a week for the first five years of the program to provide active learning and ABET training by the Chair. Mastery of the minimal lecture teaching style is required in both the TT and NTT promotion guidelines [2].

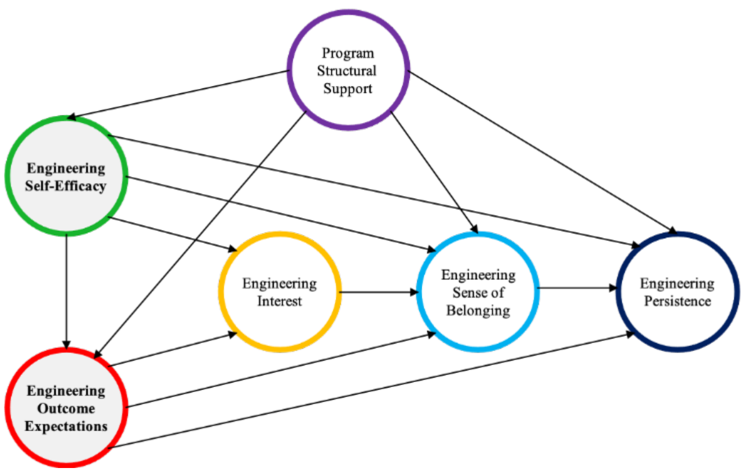


Figure. SEQ Figure * ARABIC 1: BELONG Conceptual model

Internal freshman surveys determined that female students enroll because active learning ensures a collaborative, rather than competitive, learning environment. Validated instruments, such as Student Response to Instructional Practices (StRIP) and Engineering Professional Responsibility Assessment (EPRA), confirmed that multi-semester projects like building a functional cardiograph over four semesters are engaging [3-5] and that social justice case studies like the Joint Case Study increase engineering responsibility [6], respectively. The Longitudinal Assessment of Engineering Self-Efficacy (LAESE), completed during the first and third semesters, demonstrated that women stayed in engineering at similar rates as men, even though they began the program with lower levels of self-efficacy [7].

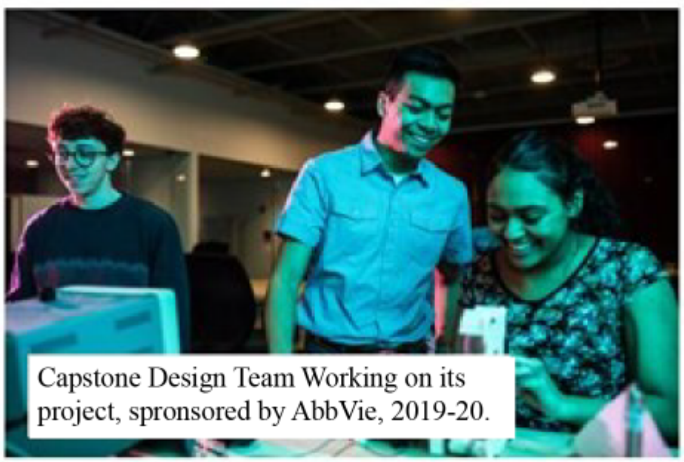
We are currently investigating the hypothesis that increased female persistence to graduation is tied to sense of belonging, initiated by the Chair through specific actions during the first semester. Our BELONG (Becoming Engineers Leading Our Next Generation) model is based primarily on social cognitive career theory (SCCT) [8, 9], which provides a framework for understanding how engineering learning experiences are translated into interest in and an intent to persist in engineering through the social cognitive mechanisms of **self-efficacy** and **outcome expectations.**

SCCT is particularly well-suited to help understand the underrepresentation of women and other minoritized populations in engineering, given that it accounts for the influence of external or contextual supports (e.g., inclusive program structures) and barriers (e.g., hostile and unwelcoming environment) on intent to persist in engineering. Greater contextual support will lead to stronger self-efficacy beliefs and outcome expectations and ultimately a stronger intent to persist in engineering in the future, whereas encounters with major barriers may inhibit the translation of self-efficacy and outcome expectations into interest and persistence. Our model also incorporates the **sense of belonging** construct, which explains how intrapersonal and environmental factors shape one's sense of belonging in engineering [10], and explains how contextual/structural factors (e.g., hostile academic environment) inhibit progress and persistence in engineering.

Impact

Program enrollment grew from 34 freshmen in 2015 to 140 students across four classes in 2023. Loyola's inaugural class graduated in May 2019, which enabled the program to seek ABET accreditation in Fall 2019. After receiving accreditation in Fall, 2020, the program became eligible to participate in national surveys. The following year, it was initially ranked by U.S. News & World Report as #39 (out of 239) 2022 Best Undergraduate Engineering Programs (No Doctorate) and #6 (out of 429) by ASEE in 2020 Percentage Bachelor's Degrees Awarded to Women. Since the program annually graduates just over 50% women, it was ranked #6 in 2021 and #5 in 2022 Percentage Bachelor's Degrees Awarded to Women. Graduates are hired at companies such as Abbott, Baxter, Credo Semiconductor, Epic Software, RJN Group, and Stantec.

Loyola Engineering Faculty at 2020 Convocation


Capstone Design Team Working on its project, spronsored by AbbVie, 2019-20.


Active Learning on the very first day of the program: August 24, 2015.

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University of Michigan

Experiential Learning

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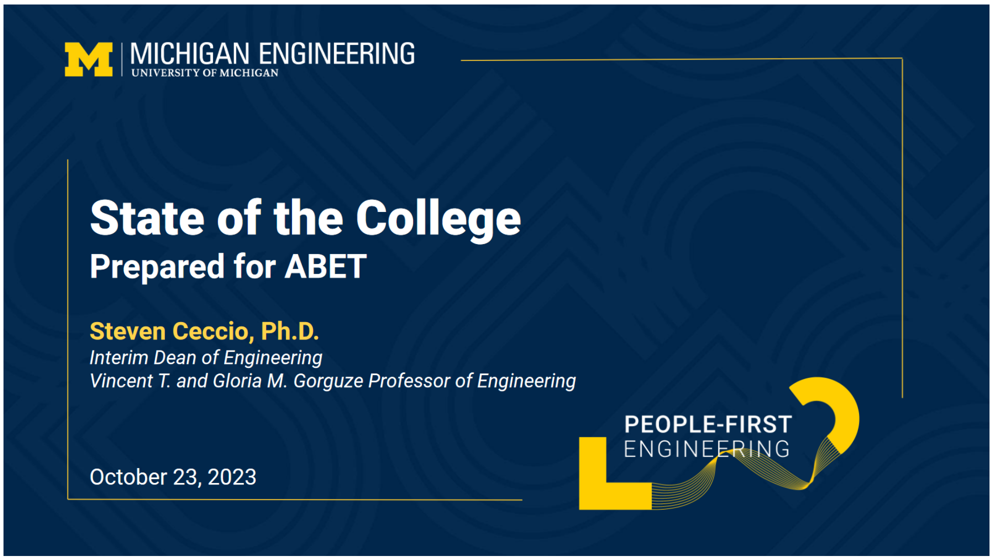
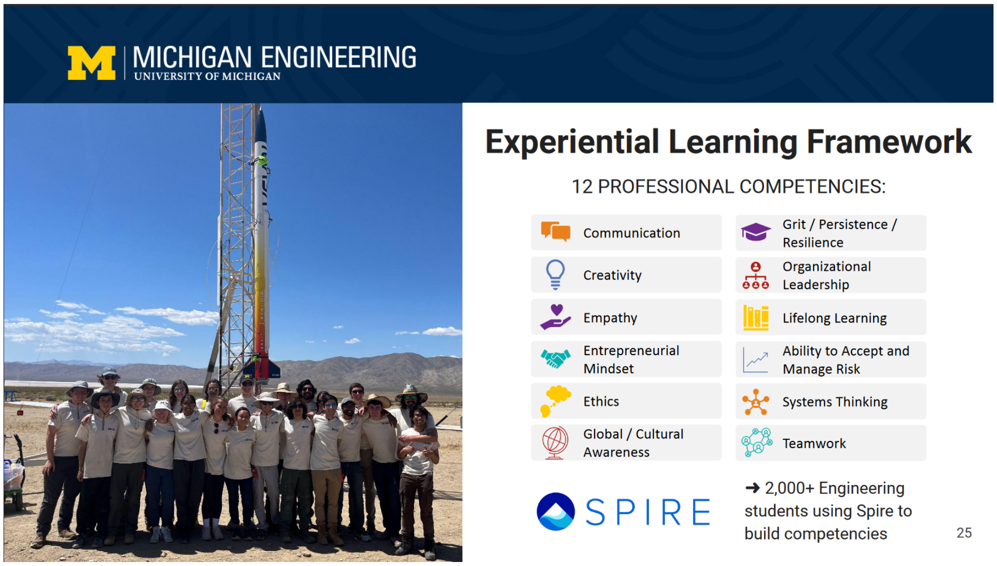
Introduction

At Michigan Engineering, our students are driven by a commitment to serve the common good through solutions that push the bounds of what is possible. We offer two linked resources to support experiential learning. The Michigan Engineering Immersed website provides program and contact information for a wide range of experiences. It is of particular interest to prospective and first-year students. Michigan Engineering Spire is a platform we've created for students to develop and communicate important professional skills (leadership, teamwork, communication, etc.) through specific experiential learning opportunities. Currently, over 2500 students have onboarded to Spire.

Based on exit surveys, approximately 95% of our students report being involved in at least one engaged learning opportunity (research, international experience, internship, etc.) during their time at Michigan. We have 26 student project teams, 153 active student organizations, over 6,000 experiential learning participants, and more than 9,000 student organization participants.

Experiential Learning Framework





Exclusivity & Inclusivity – Inclusive Teaching in Biomedical Engineering Education (IT-BME) at University of Michigan

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Brief Description

Inclusive teaching in biomedical engineering (IT-BME) aims to improve classroom pedagogy by adopting approaches that acknowledge student and instructor identity as key elements of equity-focused teaching in engineering. In so doing, inclusive teaching aims to establish a sense of community (inclusion), understand students' varied backgrounds, remove potential roadblocks to success (equity), and highlight the lenses through which the impacts of biomedical engineering can be understood (diversity). Inclusive teaching can create learning environments that positively impact student learning and promote their success both in their course learning and in their eventual practice as engineers.

Despite the positive benefits of inclusive teaching practices in engineering education, barriers to the adoption and implementation of these practices persist. While training materials, literature, and resources are available, it can be difficult to get faculty to engage due to time constraints. Adopting inclusive teaching practices would also require a substantive change in instructional style for some more seasoned faculty. Additionally, the myths of depoliticization (engineering is apolitical to social issues) and meritocracy add to the challenges.

The University of Michigan's IT-BME project aimed to address these challenges. This project sought to integrate inclusive teaching training and practices into the BME curriculum through a partnership between engineering education teaching consultants at the Center for Research on Learning and Teaching in Engineering, BME faculty, and graduate students. Through IT-BME, faculty, and graduate students underwent training through the NSF-funded Inclusive STEM Teaching Project, a massive open online course (MOOC), and collaborative learning communities. After training, faculty and students worked in joint mentor/mentee teams to revise one of the faculty members' BME courses to address key gaps in inclusivity, equity, and diversity. These collaborative teams served to lower the energy barrier for faculty to make substantive revisions in their courses while also providing graduate students with valuable pedagogical training and mentorship. These individualized experiential learning opportunities enabled the project to impart the concepts of inclusive teaching to the next generation of biomedical engineering educators. The revised courses were taught in Fall 2022 and Fall 2023. *See Figure 2 below for a visual summary of the project*.

Impact

With the support of the graduate students, faculty were able to experience success in the creation of tangible material changes to courses. Likert-style surveys were disseminated to students taking an IT-BME course in Fall 2022 inquiring about their perceptions of the inclusive teaching strategies implemented in their courses. Results indicated that the incorporation of inclusive teaching practices enhanced the BME student learning experience. Additionally, there were significant benefits to the graduate student participants. In a post-project reflection, graduate students spoke of their appreciation for the collaborative nature of the project, and they had positive things to say about the mentored and peer learning opportunities. Some graduate students also reported applying the knowledge gained in this experience in their faculty/teaching-related job search. Finally, there was overwhelming positive faculty feedback on their participation in this project.

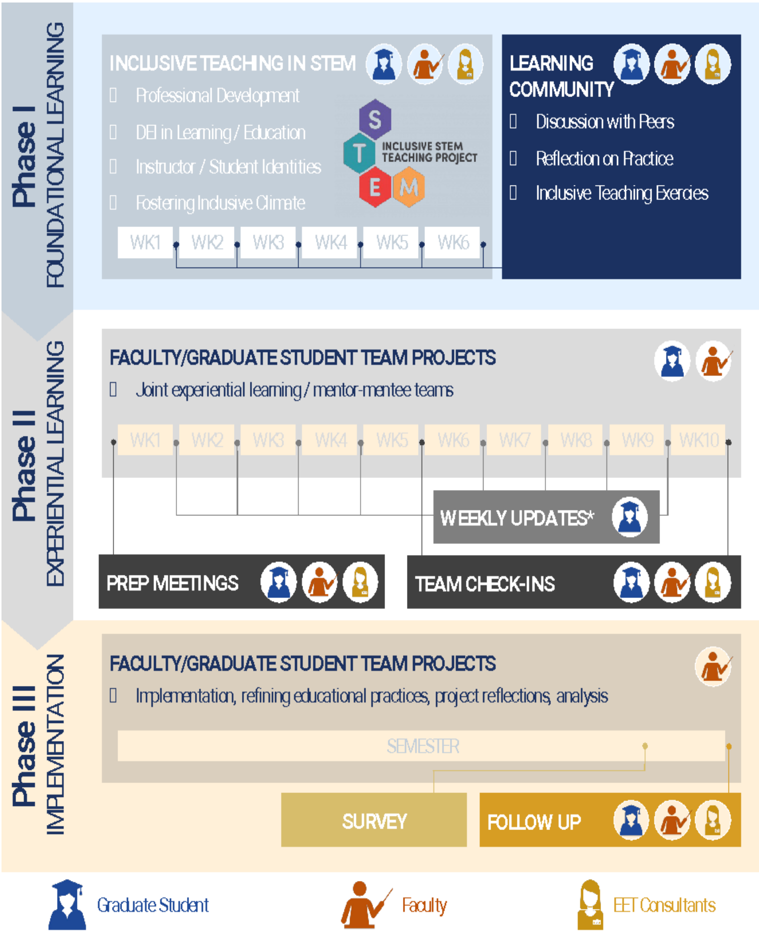

Figure 2: Timeline of IT-Eng activities including 6-week joint training, 10-week coursework development, and in-class implementation/analysis.

Curriculum Innovations: Socially Engaged Engineering & Design (SEED) Case Study Initiative

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Center for Socially Engaged Design & Professor,
Mechanical Engineering and Civil and Environmental Engineering.

The Socially Engaged Engineering and Design (SEED) Case Study Initiative partners with engineering instructors to develop original case studies highlighting the importance of socially engaged engineering processes and the impacts of engineering work on society. Their goal is to present realistic and immersive micro-historical scenarios that encourage students to engage deeply with the nuances of challenges faced by engineers. SEED Case Studies are based on real-world histories closely connected with any engineering subject, drawing on topics from professional engineering practice, engineering education, and the history of technology and society. The case studies aim to avoid the "othering" of social content by exposing students to authentic problems and enhancing their sociotechnical thinking skills, such as deep consideration of stakeholders.

The SEED case studies are conceptualized, designed, and implemented in collaboration with engineering instructors. The initiative develops materials for facilitated class sessions, asynchronous modules, and homework assignments. Instructors are motivated to use the SEED case studies to achieve their teaching goals because the cases are created or adapted to align with their disciplinary focus and course context. Integration of this content is intentionally scaffolded with a series of resources and support structures, including opportunities for instructors to observe the implementation of case studies by trained facilitators from the Center for Socially Engaged Engineering and Design. Our approach recognizes that instructors who want to highlight sociotechnical dimensions of engineering may still need to gain experience or confidence in teaching from this perspective.

The SEED Case Study Initiative has achieved 104 implementations across all delivery modes, and students have interacted over 3,000 times with case study content to date. This level of student engagement is the product of partnerships with 49 instructors representing 16 departments. Case studies have focused on sociotechnical considerations in diverse engineering spaces, including cashless payment technology in industrial operations, peer-to-peer property rental in computer science, product design in chemical engineering, control systems in mechanical engineering, and more. Initial data suggests that students perceive SEED cases to provide insights into "real world" engineering decision-making, deepening their understanding of the complexity of stakeholder needs and complicating their understanding of what it means to do engineering work for social impact.

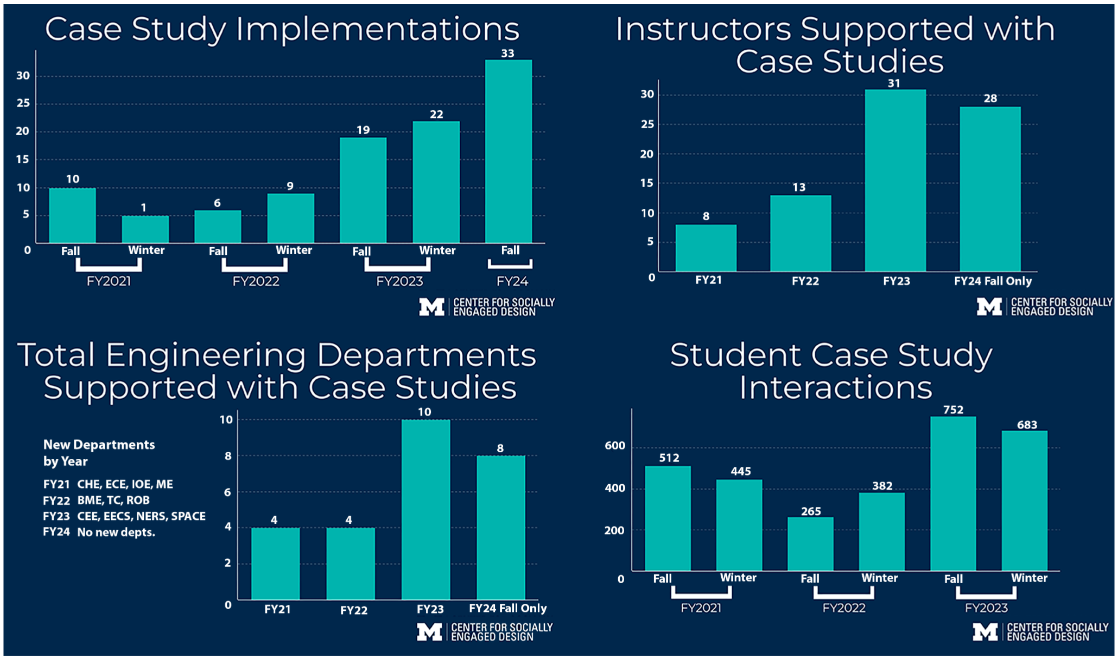

Figure 3: C-SED University of Michigan YoY Data.

Program Innovations: Center for Socially Engineering and Design (C-SED)

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The Center for Socially Engaged Engineering and Design (C-SED) at the University of Michigan advances the sociotechnical capabilities of engineers and designers by creating transformative educational programs to equip students, instructors, and professionals with the competencies necessary to engage in sociotechnical problem-solving. C-SED's approach overcomes barriers that prevent educators from including sociotechnical content in engineering curricula, courses, and co-curricular activities. C-SED's programs are grounded in research on recommended practices and span a variety of formats, including educational sessions in academic courses, co-curricular programs, digital learning platforms, and professional development workshops.

C-SED experiences are developed to align with instructors' and students' current understandings of social engagement strategies in their engineering contexts. The C-SED approach recognizes the challenges faced by educators and learners alike, including the constraints on instructor time, variability of instructor experience with sociotechnical education, the scarcity of engineering-specific sociotechnical resources, the need to avoid "othering" social topics, and the limited availability of class time to cover new competencies. C-SED faculty and staff work with educators to identify sociotechnical insertion points, which may range from design projects (e.g., considering social stakeholders) to engineering analysis (e.g., considering the context and application of engineering assumptions) to the work of engineers (e.g., considering how identity and power influence the practice of engineering). C-SED generates sociotechnical engineering content and provides instructor training, class session content and instruction, homework, and other asynchronous and online student experiences.

C-SED offers programs for students, instructors, and external learners to engage with sociotechnical engineering content in curricular and co-curricular ways. C-SED works with instructors to provide pedagogical consultation and facilitated in-class sessions that match instructor needs by creating scaffolded material and facilitated sessions that integrate seamlessly across engineering disciplines. C-SED's extensive library of content (slides, readings, activities, videos, worksheets, problem sets, etc.) focuses on topics such as contextual evaluation, understanding one's positionality within a problem space, and case studies that highlight the impacts of engineering work on engineers and society.

This year, 60% of first-year students at Michigan Engineering encountered sociotechnical topics in their first-year courses connected with C-SED activities. C-SED also brings sociotechnical methods to 4 capstone design courses across 3 engineering departments in the '23-'24 academic year. Outside design courses, C-SED is working within a growing number of technical engineering courses covering thermodynamics, controls, materials, mechatronics, and beyond. The number of instructor partners has increased 126% over 5 years, and student interactions have grown 116% in the same period.

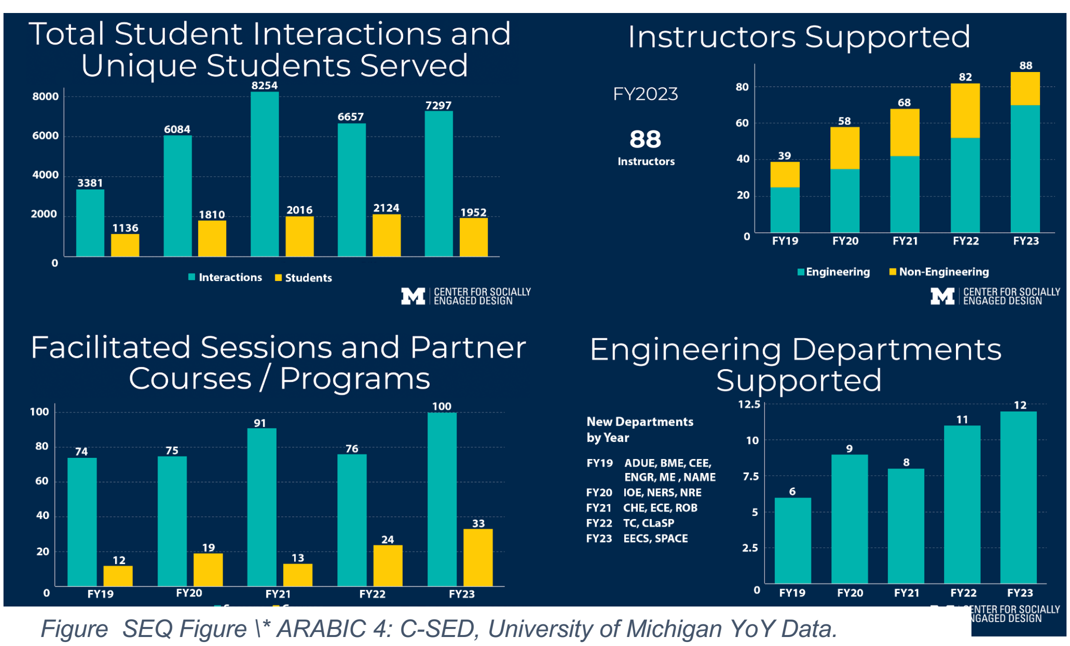

*Figure SEQ Figure * ARABIC 4: C-SED, University of Michigan YoY Data.*

University of Florida Gainesville

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When I was six or seven years old, an elementary teacher asked me to write down what I wanted to be when I grew up. I listed three options: doctor, teacher, and engineer. My teacher was surprised I knew that last term. I'm still not sure where I learned the word but I learned the spirit of engineering from my father. Although he hadn't finished high school, my father singlehandedly constructed one of the first analog satellite dishes in Puerto Rico, giving us the gift of satellite broadcasting channels from around the world. He let me help make measurements, lay out designs, and figure out how pieces of the dish fit together—a practical puzzle I could solve. I loved how we could build something useful from stuff we had at home, a few things we found at junk yards, and the odd purchase from RadioShack. When my dad had a thought for something new, he'd take the time to read everything he could find about it. He wasn't afraid to build something from his ideas. Later, when I entered college, I had that format to draw on. You don't get stuck on a problem; you go learn more. Without that example, I doubt I would have become an engineer. As I continued my education, I began adding the word "engineer" to other potential career options: medical engineer, mechanical engineer, psychological engineer. From certain angles, my jobs look like they've come from separate career paths. After my PhD in chemical and biological engineering, I worked in cell biology and taught bioengineering in Maryland. Then I went to Utah State University to research how diverse people self-advocate within engineering training programs and what keeps them from doing so (work for which I was honored with the Presidential Early Career Award for Scientists and Engineers). As a Latina first-generation college graduate, I had to learn to navigate this path through my own education and career advancement. Now I apply that knowledge to my current work at the University of Florida, where I teach engineering, research engineering education as an associate professor, and serve as associate chair of research and graduate studies. Cumulatively, my work and life have taught me the importance of lifelong learning—as well as why engineering education, mired in its rigid university-based training programs, is neither serving that need nor grappling effectively with what keeps it stuck.

Lifelong Lacking

Lifelong learning refers to an ability and willingness to keep improving and evolving within and outside formal schooling. It is essential for maintaining a competitive workforce, but engineers are not doing nearly enough of it. One analysis attributed the so-called shortage of science, technology, engineering, and mathematics professionals to graduates' inability to keep up with technical change, finding that earnings stall over time as older workers' skills grow obsolete. The National Academy of Engineering issued a report on the issue as early as 1996. It noted that a decade prior, experts estimated that half of everything a mechanical engineer knew about their field would be obsolete in seven and a half years; for software engineers, it was two and a half years. Similar concerns were raised in the academy's 2012 report, Lifelong Learning Imperative in Engineering. Not long after, an ongoing National Science Foundation (NSF) initiative called Revolutionizing Engineering Departments began offering grants to overhaul engineering curricula to be less rigid and more relevant to modern society's needs. Despite escalating calls for lifelong learning, most engineering departments are still set up to funnel people into ever-more-specialized silos, creating cul-de-sacs instead of the intersections and roundabouts necessary for engineers to stay ready to solve problems in the real world. One reason change is slow is that barriers to lifelong learning are more than simple inadequacies within any curriculum. Instead, barriers are integrated into engineering culture and coursework and grounded in assumptions about how engineering education is supposed to work, who is supposed to take part, and how engineers should behave. These assumptions are referred to as the "hidden curriculum," a term introduced in the scholarly literature in the 1960s. A hidden curriculum contains largely unarticulated cues about how people should engage with school, learning, and work. Consider the hidden curriculum in engineering conveyed in phrases like "weeder courses," or classes designed to systemically make passing them incredibly difficult. Engineering coursework is treated as an assembly line to turn students into engineers (and remove "defective products" along the way). Problem sets have fixed correct answers based primarily on technical specifications; cultural relevancy and societal impacts are considered superficial window dressing, not worthy topics, or opportunities for further learning. This hidden curriculum teaches that successful engineers proceed lockstep through traditional four-year college degrees, blinkered away from extraneous non-engineering topics. Individual achievements and academic prestige are prioritized over community. Technical solutions, as defined in an assignment, eclipse the ability to explore and integrate. Embedded in engineering's hidden curriculum is an emphasis on a mindset of "schooling" as opposed to learning (let alone lifelong learning). The schooling mindset values rote memorization over applied knowledge, grade point average over competency, grading curves over mastery, plug-and-chug equations over conceptual mapping and understanding, and individualized problem-solving over truly collaborative idea generation and formation. Each of these schooling priorities subverts outlooks that are essential for lifelong learning. To support lifelong learning, engineering educators need to develop a more nuanced understanding of the discipline's counter-effective hidden curriculum and design strategies to counter it.

Silos Stifle Passion

Harms of the hidden curriculum extend to attitude as much as knowledge and training. To find solutions, an engineer should first seek ideas from divergent sources in the world around them. The productive dance of divergent and convergent sifting requires appreciation, openness, and a certain amount of passionate interest, fueled by both curiosity and pursuit of societal good. Without this passion, there is less impetus to reach into different engineering realms. Passionate interest can be achieved via an instructional approach known as "heutagogy," or self-determined learning. That in turn demands the space, time, and flexibility to straddle different disciplinary approaches. But, within engineering departments, passionate interest is all too often subverted as degree programs pile on prerequisites and requisites and channel students into specialties with little scope to select courses of personal interest. Someone who enters a mechanical engineering program has limited options to also study policy, for example. As philosopher of engineering Carl Mitcham wrote in this journal, "Engineering programs, because of their rigorous technical requirements, tend to be the worst offenders at cutting intellectual exploration short." With course designs that have barely changed since the 1950s, engineering's hidden curriculum is one of permanent silos. And as an engineer becomes ever more specialized, their expertise is expected to become a thin, isolated pyramid of knowledge, eschewing the broad interdisciplinarity that is needed for problem-solving. But why should interests narrow with advancement? Several US engineering programs are attempting to broaden these narrow expectations. My undergraduate engineering program was highly unusual for requiring majors to have a humanities minor; it was understood that without a broader educational background it was impossible to be a "whole engineer." NSF's Revolutionizing Engineering Department programs include the Integrated Engineering Department at the University of San Diego, which is explicitly designed to provide a background in liberal arts and prepare students for a range of engineering professions. The Iron Range

Engineering program, affiliated with the Bell Engineering Program at Minnesota State University, Mankato and its community college partners, offers faculty- coached two-year internships and cooperative education programs (or co-ops) anywhere in the world. Instead of rigid, specialized engineering tracks, Wake Forest University offers a program in which students can tailor 40% of the curriculum to their interests. Colorado School of Mines and Oregon State University both offer humanitarian engineering programs, which include service learning and courses on topics like environmental and social sustainability. But even this encouraging list reflects another aspect of the hidden curriculum: recognizing formalized education without regard for other "funds of knowledge" brought in from outside the classroom. Learners' experience in sewing, carpentry, poetry, or skills passed down through generations can often help them connect the dots and become better engineers. I am not alone in finding that hobbies and passions (in my case, art and theater) have deepened my engineering work. And of course, there are engineers combining their skills and interests to help society. For example, roboticist Johnetta MacCalla, trained in electrical, electronics, and communication engineering, founded a company that uses artificial intelligence to individualize electronic coaching to help kids with diverse needs learn to code and read. To foster this, engineering schools can bring students' passions out of the informal spaces, such as clubs, student chapters, and personal projects, where they are often relegated. Students need more flexibility to follow their interests, as well as more opportunities to span disciplines and work across teams. Multiple capstone projects and customizable internships are great first steps. Advances in makerspaces and makerspace-like engineering classrooms are another possible way to narrow the divide between formal and informal learning and so enable engineers to get a better education. Loosened from a fixation on formal degree programs, universities might also expand access by allowing certification programs to "stack" into degree requirements and helping students explore engineering- adjacent careers. Industry must consider its hidden curriculum as well. Companies struggle to find enough engineers who can work with people, communicate across cultures, manage projects, and take a broad view of the social implications of their work. But job postings also demand someone with a narrow specialty—where knowledge will soon become obsolete— instead of thinking about competencies more broadly. Creating engineers who are flexible, fair, multifaceted, and eager to push the boundaries of innovation in an ever-evolving workforce requires deliberate intent. I am inspired by the inventor of the Duolingo language app, engineer Luis von Ahn, an enthusiast for engineering, online games, and languages. Von Ahn refuses to hire job candidates who are rude to the driver who brings them from the airport.

Consider the Lifespan

The most important opportunity for upending how engineering's hidden curriculum discourages lifelong learning lies in the idea of the curriculum itself. Engineering education should not stop with a degree. Universities should expand their vision beyond the stereotypical years of higher education and embrace what educators refer to as "K–gray": from early elementary school education into retirement. Recently, with the associate dean for workforce development and interim dean of my college at the University of Florida, we began the process of outlining a continuum model of an engineer's development—one that considers who students are before and after they pass through our degree programs. We studied our existing offerings plus overarching goals to see where our university placed its resources. We are still iterating the model but I am inspired by its initiative and insight. This kind of regular, formal examination of systems and structures can illuminate the hidden curriculum and so shed light for new solutions and better strategies. We were surprised to find that our offerings focused almost exclusively on undergraduate and early graduate training, with a smattering of outreach to local schools. There was little emphasis on upskilling following a terminal degree, and few offerings geared toward teaching habits and mindsets for lifelong learning. Again, industry has an important role to play. Engineering faculty and professional engineers rarely communicate, which means faculty know too little about industry's changing needs to adapt their classes, and industry lacks ready access to new research or the academic programs training their future employees. Industry could codesign classes with faculty, which would benefit working engineers, educators, and those in training. Such practices might even help solve two problems at once, since midcareer, senior, and retired engineers are seldom given mini sabbaticals to expand their expertise. Going further, industry could fuel a virtuous cycle by partnering with educational institutions throughout the K–16 spectrum. Both researchers and students are increasing access by infusing engineering knowledge into online resources and social media. But as valuable as they can be, content on platforms such as YouTube, Instagram, and TikTok are often created for peers or near-peers and are less likely to reach younger or older learners or those who do not speak English. Any discussion of expanding lifelong learning opportunities must also bear in mind that some individuals and social groups have more access to courses, certifications, and other opportunities than others due to time, funds, and awareness. Efforts to expand lifelong learning should also go beyond university classrooms and faculty offices into the community. Earlier this year, I was part of a gathering at the White House to discuss how to build the next generation of Hispanic leaders in engineering. A family of four was among the participants. The father, a truck driver, reported he'd never actually met an engineer before; his hope was to help his children gain the education required for a better life. His experience meeting engineers allowed him not only to imagine his children becoming engineers, but to imagine becoming one himself. Not all parents need to be engineers, but parents' familiarity with and attitudes toward engineering need to be considered by admissions officers and other outreach programs. More broadly, universities should consider what influence they can have on families and social circles that encourage a child's inclination to learn. When I reflect on how I learned to think broadly and persevere, I am grateful to my parents, who taught me to love trying out new things, lessons that helped counter the lockstep assumptions in my engineering curriculum. Their example has helped convince me that foresight and planning can help universities intentionally shift the curriculum (explicit and implicit) to encourage lifelong learning rather than thwart it.

Georgia Institute of Technology – VIP Consortium

STRATEGIC PLAN

Introduction

This strategic plan provides a blueprint for the VIP Consortium's work over the next five years and a vision of the Consortium's future. We have formulated the objectives and priorities outlined in this document from two primary sources: (a) ideas originating from VIP site program coordinators and gathered during brainstorming sessions held at the Consortium's annual meetings, and (b) through direct communication between the Consortium Executive Director, the Executive Steering Committee, and the Board of Directors.

About the Consortium

The VIP Consortium is a nonprofit alliance of higher education institutions with Vertically Integrated Projects (VIP) programs. In VIP programs, teams of undergraduate students – from various academic years and disciplines – work with faculty and their graduate students on ambitious, long-term, large-scale projects. Undergraduates are directly involved in the research and innovation process, applying their knowledge and insights to the most challenging unsolved problems. The VIP model has been studied and refined for more than 20 years. Unlike many other high-impact programs in higher education, VIP is accessible, equitable, and scalable. In 2015, a $5 million multi-institutional grant from the Helmsley Charitable Trust helped spread the program to a wide variety of institutions, which collectively became known as the VIP Consortium. The VIP Consortium was launched as a 501(c)3 nonprofit organization in 2019, with directors of all VIP programs serving as the nonprofit's academic advisory council and as members of the VIP community. The

Consortium's objectives are to provide mentoring, tools, and other resources to help institutions start and sustain successful VIP programs. Through the VIP Consortium, affiliated programs worldwide share best practices and collaborate on the continued improvement and dissemination of the VIP model.

VIP Formula for Success

- Faculty create projects around their scholarly interests, bringing their expertise and enthusiasm to each team. Their teams' efforts help advance their long-term scholarship and research and support the work of their graduate students.
- Undergraduate students choose from the various VIP projects offered on their campuses based on personal interests. They earn academic credit for their work and can participate on a VIP team for up to three years. Participation in VIP projects provides the time and context for students to:
    - gain deeper insights into their field of study,
    - learn and practice professional and research skills,
    - make substantial contributions to solving real-world problems, and
    - experience different roles on large, multi-disciplinary teams.
- The long-term nature of VIP projects creates a unique environment of mentorship: faculty and graduate students mentor teams, experienced students mentor new members, and students move into leadership positions as others graduate. This structure provides opportunities for students to develop leadership and collaboration skills. It also reduces faculty workload, allowing more time for meaningful engagement with many students.
- Students share in any intellectual property that results from their work on VIP projects, fueling interest in entrepreneurship. Many teams also have external industry and government partners.

As a result, VIP programs have been shown to have several benefits for students, including:

- Improved retention and increased graduation rates,
- Enhanced critical thinking and problem-solving skills,
- Increased confidence and self-efficacy,
- Higher job placement rates,
- Increased opportunities for professional development, and
- Greater awareness of the impact of their research and education on society

Our Vision: Systemic Reform of Higher education globally

Widespread adoption of the VIP model is the primary purpose of the Consortium. The members of the Consortium envision university education that effectively prepares all students to succeed in their careers and life pursuits, to engage in multi-disciplinary approaches to innovation, to collaborate with people from diverse backgrounds, to become knowledge seekers and producers, and to be able to make meaningful contributions to solving complex challenges in the workplace, in their communities, and the world.

Our Core Values

As a collective of colleges and universities, the VIP Consortium believes that by working together, it can make fundamental changes to higher education. Outlined below are its core values that guide our every decision and action; they are the foundation of our success.

Experiential Learning

At its core, the Consortium values experiential learning, allowing students to apply their knowledge and skills in real-world settings. Prospective employers from industry and other sectors instantly recognize that VIP teams function almost precisely like teams in the workplace. They value the teamwork and leadership skills students develop over the progression of semesters that they earn academic credit working on a VIP project.

Equitable Participation and Outcome

The Consortium's mission is to provide opportunities for success for all students, regardless of their background. We believe student success on VIP teams correlates more closely with project enthusiasm than prior experience or Grade Point Average (GPA). We encourage VIP programs not to consider GPAs, resumes, or letters of recommendation in student selection. We believe eliminating these practices is essential to removing barriers to participation in VIP teams. Instead, we recommend choosing students to participate based on their eagerness to embrace the project's challenges.

Innovation

An essential characteristic of a VIP team is that the work is embedded in a faculty member's scholarship and exploration efforts. This characteristic implies that the student is immersed in a culture of innovation and has the opportunity to collaborate and learn directly from experienced researchers. By their nature, VIP teams have the multidisciplinary breadth, disciplinary depth, and continuity that enable them to contribute significantly to the field and society. These contributions can take many forms, such as discovering new knowledge, developing new products and services, or improving existing commercial processes.

Continuous Improvement

The success of the VIP Consortium and its mission critically depends on the continuous improvement of the VIP model as it is implemented at member universities, which requires rigorous assessment and sharing of effective practices among VIP members. TheVIP Consortium is committed to facilitating the engagement and interaction of its members to refine the VIP model, research and develop assessment methods and tools, and support one another. The core values above define us and what the Consortium stands for. They are the foundation of our success and will continue to guide us as we move forward. In the coming years, we will focus on strengthening and using our core values to guide moving forward.

Our Mission, Objectives and Priorities

In alignment with its core values, the VIP Consortium's mission is to create an ecosystem and enabling infrastructure to support the expansion, success, promotion, and implementation of Vertically Integrated Projects (VIP) Programs at colleges and universities worldwide.

Toward this mission, we have recognized four essential objectives that are our primary focus in enhancing the operational capabilities of the Consortium.

VIP Program Growth & Development

Grow and expand VIP programs on campuses globally – promote the VIP model and its essential elements as the backbone for established sites while implementing new programs to reach more students.

Priorities:

Site Recruitment

The Consortium will maintain a list of prospective VIP sites and build awareness of VIP at targeted universities. We will enlist existing members to serve as *ambassadors*, who will share their experiences, explain the value of implementing the VIP program, and assist in recruiting new prospective members.

Effective Practices

The Consortium will promote effective practices in VIP programs among member sites by:

- Developing a VIP Handbook, documenting program guidelines for setting up and maintaining a VIP Program,
- Deploying a standard set of Student Evaluation Tools across all VIP sites as a platform for normalizing student assessment methods and collecting impact data,
- Implementing a Faculty Training & Development Program for program coordinators and faculty team leaders.
- Devising a Quality Framework, enlisting the most senior program coordinators to coach other program coordinators and monitor adherence to their program with effective practices.

VIPC Member Journey

The Consortium will hire staff who will serve as coaches and trainers to support member sites through six stages of awareness and program maturity: Awareness, Prospect, Onboarding, Active, Thriving, and Contributing. A *Member Journey Map*, which depicts the existing and planned activities for supporting VIP Consortium members, can be found in the Appendix of this document.

VIP Community

Build a vibrant and supportive community of VIP sites and program coordinators who share knowledge, collaborate on research, and innovate to improve student outcomes.

Priorities:

Meetings & Events

In addition to the regular annual meetings of VIP program coordinators, the Consortium will support and enable regional conferences and events for program coordinators from existing and new sites to develop relationships and share knowledge within specific regions.

Online Community

The Consortium will use social media platforms and online communities to create a vibrant and supportive community for VIP program leaders, students, and alums. We will curate and moderate LinkedIn, Facebook, and Instagram content and leverage Slack to facilitate discussion and collaboration. Our goal is to provide a space where members can connect, share resources, ideas, and experiences, and learn from each other continually.

Competitions, Awards, & Recognition

The Consortium will expand participation in its annual VIP Innovation Competition, its showcase event held during the annual meeting. The competition encourages VIP programs to develop new and innovative ways to improve student outcomes and rewards students for their individual and team contributions. The long-range goal is to have *all* member sites put forth at least one team. The Consortium will also develop other forms of recognition for students, program coordinators, and VIP sites, including a badge program for recognizing programs as they advance through stages of maturation and contribute to the Consortium.

Collaborations

The Consortium will continue facilitating collaborative research and publications among VIP program leaders in targeted research areas, such as sustainable development, artificial intelligence, and VIP in the humanities. The collaborations help to advance the state of knowledge in these fields and relate directly to the Consortium’s core value of innovation. Also, in alignment with our core value of continuous improvement, the Consortium will support sharing effective evidence-based practices among VIP programs leaders.

VIP Brand & Outreach

Promote and maintain the meaning and quality of the VIP brand by raising awareness of VIP and the Consortium's activities, building relationships with key stakeholders, and developing and implementing programs and initiatives that align with the Consortium's mission, such as creating a social media campaign and curating the VIP Consortium website.

Priorities:

Fundraising

The Consortium will focus on raising funding to support expanding the number of VIP sites and ensure its long-term sustainability as a stand-alone non-profit entity independent of any specific university.

Industry Partnerships

The Consortium will facilitate partnerships between companies and VIP teams and encourage companies to donate equipment, provide advice, and fund research. The Consortium will also support the commercialization of intellectual property developed by VIP teams.

Strategic Alliances

The Consortium will reach out to other organizations that can help it achieve its mission of transforming higher education. Examples include the Association of American Universities (AAU), the Accreditation Board for Engineering and Technology (ABET), and the American Society for Engineering Education (ASEE).

VIP Branding

The Consortium will create a comprehensive branding toolkit for the organization and VIP sites. The toolkit includes guides on brand identity, website design, and social media presence. It is intended for marketing and design professionals responsible for branding VIP sites.

VIP Consortium Operations

Develop and maintain organizational capabilities required to execute annual and strategic plans.

Priorities

Finance & Legal

The Consortium will continue to develop and maintain fiscally responsible policies and practices necessary to maintain IRS 501(c)3 status compliance and sustained positive member experience.

Governance

To ensure accountability, transparency, and efficient management, the Consortium has formed an Executive Steering Committee. This committee comprises the most seasoned and knowledgeable Site Program Directors, who champion members' interests and provide support in operational planning. The Consortium will also provide regular financial and operational reports to the Board of Directors and hold board meetings open to the public.

Information Technology

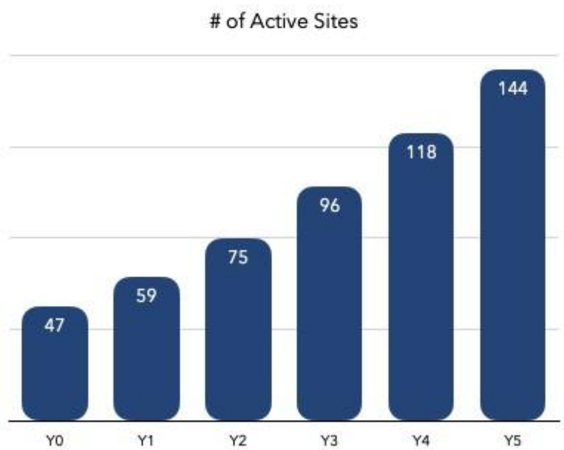
The Consortium will deploy IT systems and software to improve communication and collaboration among members by providing them with access to shared databases, communication and assessment tools, and collaboration platforms. The Consortium will select and deploy a Customer Relationship Management (CRM) system to track interactions with VIP Consortium sites to provide better service and support. The Consortium will also upgrade the VIP website to make it more user-friendly and informative for VIP member sites, potential new sites, partners, sponsors, and the general public.

Agile Operations Planning & Management

This strategic plan is relevant and valuable only to the extent that operations planning and management facilitate the continuous engagement of stakeholders in defining priorities, making decisions, and collaborating when necessary. To accomplish this, we adapted Agile Scrum as the basis of our operations planning and management process: priorities are linked to *tasks* maintained in Asana, our primary work management tool, subdivided into small, manageable *sub-tasks* that are assessed, prioritized, scheduled, and completed on a monthly or quarterly basis, allowing for maximum flexibility and adaptability.

Activity Plan

The Consortium's successful mission achievement primarily manifests as a growing membership. Currently, the Consortium boasts 47 member sites, with a handful considered thriving and actively contributing. Our goal for 2028 is to have approximately 150 active sites, indicating an annual growth rate of about 20%. The growth plan illustrated in the adjacent graph outlines our expansion targets. These numbers result from efforts to increase site numbers in various regions, including Africa, Asia, Europe, South America, and the United States. Additionally, they'll result from the touchpoints developed as part of Objectives 1 & 2 and outlined in the VIPC Member Journey Map.



Concluding Remarks

This strategic plan is a blueprint for the VIP Consortium's operations over the next five years. Our specific aims include expanding the Consortium, enhancing its member community, increasing awareness of VIP Programs beyond the Consortium, and maintaining streamlined fiscal operations. Our strategic plan outlines these objectives while emphasizing the importance of adaptability and execution. Our strategic plan will remain *dynamic*: continuously reviewed and updated to align with the Consortium's evolving objectives, priorities, and resources. The VIP Consortium believes that its strategic plan and agile operations management approach are the most effective means to fulfill its mission: creating a unique research and educational ecosystem and infrastructure to support the growth, promotion, and success of VIP Programs worldwide. We are fully committed to executing this plan and achieving our objectives, and we invite readers to join us in this endeavor.

Northeastern University – Bala Maheshwaran

Author

Professor Bala Maheshwaran,
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Active Learning

Project-Based Learning (PBL) has been a transformative force in my teaching, reshaping both my approach and my students' educational journeys. Embracing PBL necessitated a departure from conventional teaching methods, heralding a shift towards student-centered learning. Its origin lies in the belief that education should empower students as active learners, critical thinkers, and problem solvers. PBL offers a structured framework that nurtures engagement, collaboration, and the practical application of knowledge in real-world contexts, establishing itself as an indispensable tool for educators worldwide. This approach equips students with the essential skills and adaptive mindset required to thrive in an ever-evolving world.

For me, personally, implementing Project-Based Learning has proven transformative in my role as an educator. It has enabled the creation of a dynamic, student-centric learning environment where students become active architects of their education. Through project-based activities, my students have honed critical thinking skills, deepened their understanding of subject matter, and mastered effective collaboration with their peers. PBL also facilitates differentiation, allowing students to explore their interests and work at their own pace within the project's context.

In my cornerstone freshmen engineering courses, I've introduced theme-based and team-based Project-Based Learning, yielding remarkable successes in teaching and learning outcomes. Over the past six years, my freshman undergraduate students have achieved remarkable feats, publishing and presenting over forty papers in peer-reviewed conferences and proceedings, a remarkable accomplishment for students at such an early stage of their academic journey. Furthermore, it has afforded me the privilege of guiding numerous students to ASEE conferences, enriching their educational experiences and immersing them in the authentic professional world.

Impact

This educational approach has had a profound impact on student performance, augmenting their knowledge and honing their skills. It has elevated the quality of the learning journey, fostering heightened engagement and motivation, resulting in a more captivating and effective educational experience. What's more, it empowers students to learn at their own pace, fostering inclusivity within the learning environment. Instructors also reap the rewards of its adaptability, enabling tailored instruction to meet individual student needs, leveraging their prior backgrounds for effective support. This adaptability becomes especially crucial during moments of crisis or disruption, such as a pandemic. This learning experience instills students with the confidence to navigate real-world scenarios as they transition from the classroom to internships or professional roles. Notably, stakeholders, including students, express high levels of satisfaction due to the positive impact of this Project-Based Learning approach. Most significantly, students undergo a profound transformation in how they learn, interact, and develop into fully independent engineers by the time they graduate.

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Bucknell University – ASEE Report Nugget

Author

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Department of Electrical Engineering

Vignette: Institutional innovations in a single engineering department.

Several years ago, the Electrical and Computer Engineering (ECE) program at Bucknell University took a hard look at ourselves and realized that the curriculum was modeled after those at research universities. As engineering in a liberal arts institution, this created a misalignment with our institutional mission and the image we projected to prospective students and their parents. We undertook significant curriculum reform that was informed by the image of a tapestry that has strong binding threads, the warp, over which a picture is woven. We identified seven topical 'threads' on which the curriculum was built: science, math, electronic systems, information systems, design, professionalism, and elective choice. We also analyzed many years of data collected as part of our ABET effort to understand where the program was and wasn't working for students. Three years of planning for curriculum change were followed by four years of implementation and at the end of this process we had significantly revised the ECE curriculum.

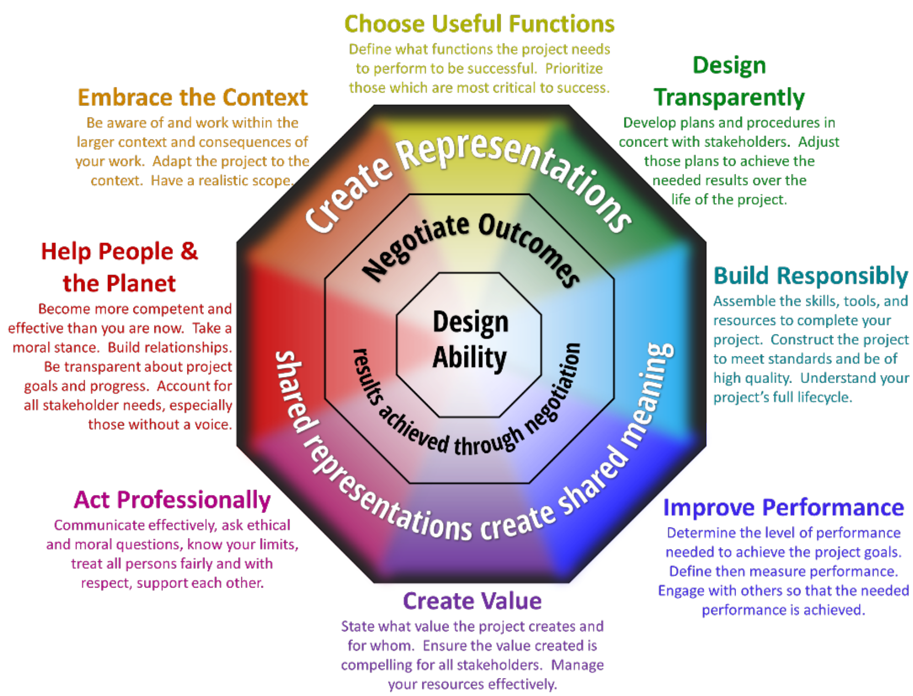
What have the results been? Developing coherent curricular threads allowed a significant reduction in the complexity of the curriculum. In terms of prerequisite courses that were not contiguous in time, we dropped from 14 'semester-gaps'—the sum of the number of semesters between a prerequisite course to a required course across the curriculum—to four. The curricular complexity [*Heileman et. al., Does Curricular Complexity Imply Program Quality?, Proc. ASEE Ann. Conf., New Orleans, 2019*] also dropped: 25% in degree and 50% in average path length. Since both students and faculty wanted more design, we moved from a 'bookend' model to having design in every year of the curriculum through our design thread, expanding from six credit hours to twenty. Since both students and faculty wanted courses on advanced topics, we went from three to twelve credit hours of technical electives. The increase in technical electives enabled the program to offer specialty 'concentrations' to students which improved advising and created more specialized degrees despite being a small, nine faculty member program. To prepare students many ECE courses were moved from the junior to the sophomore year. Since the total credits of the curriculum were fixed these gains were balanced by losses in general engineering courses and moving some ECE courses from being required to electives. This shift also balanced coverage of ABET outcomes; before the change 41% of assessments focused on outcome (a) with only 3% for outcome (h). After the change the most assessed outcome was (1) at 25% and the least measured was outcome (4) at 7%.

These changes made the curriculum more accessible to students. By offering some courses more frequently students who study abroad or are scholarship athletes have more flexibility in scheduling courses to meet their schedule. The two degree programs—electrical and computer—are now nearly identical in the first two years, allowing students more time to choose which major they desire. The increase in open electives has made it easier for students to transfer into the program, pursue any minor, study abroad, and for students who get out of sequence—often students who are first generation or from underrepresented groups—to graduate on time.

Vignette: How a design sequence has successfully incorporated social issues and student-centered learning.

The Electrical and Computer Engineering (ECE) program at Bucknell University has run a multi-year experiment in action research to redefine a four-year design sequence that provides increased opportunities for technical design closely tied to societal contexts. By expanding from a bookend model of 10 credit hours to 20 credit hours of design across all four years, students have opportunities each year to undertake self-guided projects supported by active learning that addresses real-world challenges.

Guiding this 'design thread' is a framework of eight 'design lenses' that students use to frame design challenges: create value, act professionally, help people and the planet, embrace the context, choose useful functions, design transparently, build responsibly, and improve performance. To enable students to see design from these eight perspectives students are taught to express their design through graphical and tabular graphical representations. Each lens has a set of representations, such as block diagrams for design and system maps for context. Throughout their four years, students develop their ideas through these representations, which serve as centers of conversation in ongoing dialogs and negotiations about their projects. In this way design becomes a dynamic social activity rather than an engineering process to produce a deliverable for a client. The use of a common framework and consistent representations supports transfer between courses.



The organization of the design course sequence also guides student development. In the first year, students first learn fundamentals of engineering design on two-person multidisciplinary teams, then focus on design in ECE by building an internet-of-things device. In the second year students adopt the design, implementation, and performance lenses as they go through end-to-end prototype development of an electronic sensing and display platform that reuses and extends the project from their first year course. The third year focuses on the value, people and planet, and context lenses by having students design towards a United Nations Sustainable Development Goal. In their fourth year the capstone sequence integrates all lenses through externally sponsored, large-scale projects. Students explore how their project impacts multiple stakeholders and the environment and are urged to explore multiple ways to create value. Active learning is used throughout the sequence. Activities are heavily scaffolded in the first two years but give student teams increased agency and autonomy in later years.

The impact of this effort has been significant, but often difficult to quantify precisely. In exit surveys, the design courses are highly praised by students and qualitative data shows they make significant progress on professional and transferable skills. The quality of projects has significantly increased over time. Since each student creates their own sensing platform in the second year, the professional finish and function of these projects serve as a showcase to help students land competitive internships. Having design in all four years has created new community among faculty, who meet informally each week to brainstorm new ideas and make adjustments to the courses. This cohesion also ensures that the courses form a coherent sequence rather than a set of stand-alone design experiences. Feedback from project sponsors and alumni are positive and help to drive ongoing changes to the design sequence.

Edmonds College – Engineering as an inclusive mindset

Author

Mel Cosette,
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TITLE: DIVERSITY, EQUITE, INCLUSION (DEI) AND ANTIRACISM ONLINE COURSE

Brief Description

During spring and summer quarters in 2023, Dr. Yvonne Terrell-Powell, Vice President of Equity, Inclusion and Belonging at Edmonds College, located in Lynnwood, WA, worked with faculty and staff to create and pilot a DEI and Anti-Racism Online Course to twenty-four new faculty and staff that joined Edmonds in fall 2022. As of fall 2023, approximately 150 are enrolled in the self-paced, 2.5-3-hour course supported by a facilitator, and participants have up to 6 weeks to complete. This online course was developed to meet the requirements of Washington State Law 5227, "…to provide professional development focused on diversity, equity, inclusion, and anti-racism for faculty and staff" and to enhance our continued commitment and the implementation of strategies that address inequities, close racial equity gaps and advance student success for all.

Post-evaluations from the pilot offerings resulted in positive course feedback and improved self-reported scores across several vital DEI topics. Consequently, the college now offers the course to employee groups across our campus. The course provides participants with an opportunity to learn critical information needed to support their actions as they address "structural racism against all races and promote diversity, equity, and inclusion while improving academic, social, and health and wellness outcomes for students from historically marginalized communities . . . and focus on elements that support commonalities and humanity (5227)."

Foundational course topics include terminology, microaggressions, land acknowledgments, racialized trauma, and equity-mindedness that support our commitment to DEI, anti-racism, and student success. Through ongoing and active conversations, participants who complete the course have the opportunity to practice, reflect, and develop a DEI and Anti-Racism Student Success Action Plan.

Impact

The largest increases in self-reported knowledge scores across employee types from the pre-survey to the post-survey were for the foundational DEI topics: Raven Model, Equity Mindedness Principals, and Writing Their Own DEI and Anti-

Racism Student Success Action Plan. The Raven Model allows participants to learn about microaggressions and how to respond to them. The Equity Mindedness Framework and DEI and Anti-Racism Student Success Action Plan enable participants to apply equity-mindedness principles to their day-to-day work, focusing on improving students' success and closing equity gaps. These knowledge score increases suggest that those three areas (the Raven Model, Equity Mindedness Principals, and Writing Their Own DEI and Anti-Racism Student Success Action Plan) are where there was the greatest knowledge gain for employees.

The college also took note of the highest self-reported knowledge scores across employees before participating in this course. These were for the topics: DEI Terminology, The Importance of, and How to Write, Land Acknowledgements, and Racialized Trauma and Its Impact on Students. While there were increases in scores from the pre-test to the post-test, the higher initial scores suggest that the college is doing well communicating and applying these topics on campus.

Testimonials

"Edmonds College is committed to student success and has a history of working to advance DEI and antiracism efforts. Offering this course provides an avenue for faculty and staff to enhance their work and lean into a future of inclusive excellence and student success."

Dr. Amit B. Singh,
President,
Edmonds College

"I completed the DEI class in 2023, and I found it to be a well-developed course from which I gained great knowledge and benefits. As a new faculty member who recently joined the education field, this class provided me with a comprehensive overview of DEI and how to effectively implement it in teaching and course development to enhance students' learning experiences. I would definitely recommend this course to all faculty members."

Yiren Yue,
Biology Faculty

"I took the DEI training, and I was pleasantly surprised. The training was well thought out and sensitive in the vocabulary used and the examples provided. The training provided insight into the lesser-known nuances of being a POC and a WOC, such as microaggressions concerning the hair of a WOC. The training explained the emotions centered around jokes and differing comments that allowed the students time to ponder and deliberate on the intentions of many jokes and comments. I appreciated the comprehensive perspective of the video, introducing DEI plights from various perspectives. As an instructor, I also appreciated the opportunity to delve into deeper DEI understanding, the homework. Encouraging the student to explore deeper meanings of the terminology and concepts presented allowed the training to become solidified. As a BIPOC member, I appreciated the DEI training and I look forward to engaging in the training every year. I am excited to know that my colleagues will also be taking part in this training."

Roxanne Green, Ph. D.
Full-time Faculty,

Elizabethtown College – Etown MBL

Contact

Sara Atwood,
Dean of Engineering & Computer Science,
Professor of Engineering

Elizabethtown College offers a B.S. in Engineering with an emphasis on a multidisciplinary engineering foundation paired with eight concentrations in a variety of disciplines. The foundational physics and engineering science courses in the first two years and beyond are taught with a **competency-based assessment** approach that intentionally links skills mastered through course sequences and allows for a degree of student self-pacing. The curriculum also includes six semesters with multidisciplinary design projects and an active-learning pedagogy infused throughout the curriculum. Although not a highly selective program, over 86% of Etown Engineering intended majors graduate with an engineering degree, with over 94% of those obtaining their degree in four years. This is thanks to Etown's student-centered pedagogy, intensive advising, multidisciplinary curriculum, and competency-based approach to the engineering science foundations.

Etown's engineering program requires that students demonstrate mastery of the most critical prerequisite material before moving forward to the next topic, ensuring that all students in the course, regardless of background and circumstances, have a solid foundation upon which to build success in future courses and more advanced topics. The students cannot attempt to 'partial credit' their way to a higher-level course; rather they are given the time, space, and individualized support to achieve mastery of the foundational skills and concepts. While the approach doesn't change that the 'A' student masters all topics in a course, it substantially changes the experience of the 'C' student: from not fully understanding any course material, to fully mastering the most critical and foundational skills, even if it takes all term.

As a result of this structure, Etown has seen a transformation in students taking ownership of their learning. Students are motivated to learn rather than to achieve a meaningless grade; they understand how topics are connected; they selectively spend time on the skills they still need to master; they see the instructors not as adversaries but as partners in achieving their success. Instructors have observed significant behavioral shifts, including substantially higher engagement in office hours, increased time spent practicing problems, and improved self-awareness of students' own understanding and learning process.

While competency-based learning is known to be pedagogically effective, Etown Engineering is relatively unique in the extent to which it has been able to transform the student experience by infusing the approach across foundational coursework and through disciplinary sequences from the 100 to 400 level. Etown faculty have authored a book chapter on the topic, won awards at ASEE, and have given over 10 workshops at other institutions on their approach.

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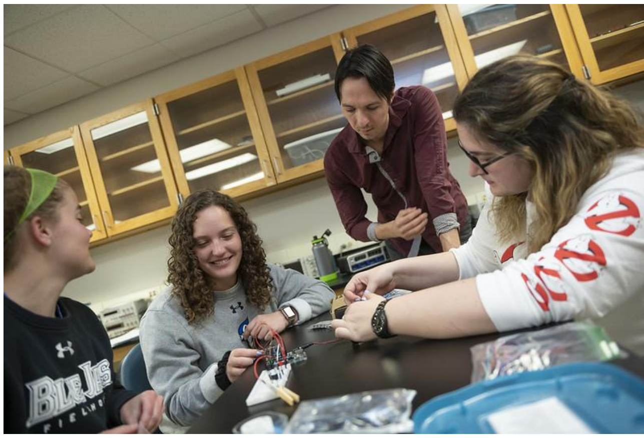

Minnesota State University – Iron Range Engineering

A nation-wide cooperative engineering education for community college graduates

Minnesota State University, Mankato’s Iron Range Engineering program delivers an upper-division engineering education that is centered on student experiences working directly in industry through co-op employment. Students work in industry for the last two years of their education while being supported in their technical and professional development by professors, learning coaches, and their own peers through the use of digital communication. Crafting a student learning experience that is centered on engineering practice from all of its perspectives, this program aims to better transition the student who entered, to the practice ready engineer who graduates. The program is designed to be relevant, interesting, supportive, inclusive, and financially sustainable. Students earn a BSE, with a major in integrated engineering.

The work-based learning experience involves the student gaining engineering practice perspectives at all steps. The program delivers a “direct” learning experience where the profession is experienced in-situ. The learning experience opens doors for greater access to engineering education. Aimed at community college graduates, it serves a more ethnically and gender diverse student body. It is also creating opportunities for place-bound individuals to earn the majority of their education near their homes. Further, the financial model (students earn while on co-op) increases access to higher education without crippling student loan debt.

Entering students have completed their lower division studies at community colleges and from across the United States. They enter a one semester development called the “Bell Academy”. In this bridge semester, they polish the skills necessary to succeed at high levels both professionally and technically as self-directed learners, working as unpaid engineering interns as they acquire and prepare to enter their first paid co-op. Satisfactory competency achievement is necessary to move from the Bell Academy to paid co-op placement.

In addition to 10 “professors” (PhD level engineers) who create, facilitate, and support the self-directed learning of technical competencies and give verbal exams to students, the program has 10 engineers from practice called “facilitators” who act as learning coaches. These coaches mentor students in their professional and engineering design development through frequent encouraging feedback on the students’ reflection journals and design documentation. Feedback is both in writing and face-to-face electronically. Learning coaches also liaise with company supervisors and facilitate peer-to-peer support teams.

Features of the program include models for professional development, self-directed learning development, structured reflection, technical competence development (all technical courses are 1-credit), culture management, leadership, innovation, design learning, and inclusivity.

Giving individuals the liberty to pursue their own path to engineering excellence

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LEARNING WITH ACADEMIC PARTNERS (LEAP): A NEAR-PEER MENTORING PROGRAM TO SUPPORT ACTIVE LEARNING IN FIRST-YEAR ENGINEERING COURSES AT MICHIGAN TECHNOLOGICAL UNIVERSITY

The LEAP Program was established as part of an evolution of the first-year engineering program in the Fall of 2017 at Michigan Technological University. At this time we transitioned from an active classroom to a flipped classroom environment and created a new active learning space with a larger capacity of 120 students. To support the students in this new environment, we incorporated a near-peer mentoring program, the LEarning with Academic

Partners (LEAP) Program, directly into the structure of our first-year engineering courses. The courses consist of two meeting types: studio sessions and LEAP Sessions [1]. The studio sessions meet twice weekly for 110 minutes each time and contain five groups of up to 24 students, 120 students total. The studio sessions are run by a faculty member whom the five LEAP Leaders support. The LEAP Leaders are undergraduate students who have completed the first-year engineering courses and are assigned to one group of 24 students. During the studio sessions, LEAP Leaders actively monitor and guide their students through in-class activities in which students apply the knowledge and skills learned in their pre-lesson materials and activities. Students work in semester-long teams of three to four students.

Figure 5: Studio Session with 120 students, one faculty member and five LEAP Leaders

The LEAP sessions are 50-minute sessions that the LEAP Leaders plan and facilitate for their 24 students in separate classrooms. These LEAP sessions are similar to Supplemental Instruction sessions and are designed to be active and collaborative review sessions for the content covered in the studio pre-lessons and sessions. Active participation in LEAP sessions is required and is 10% of the overall course grade. Outside of class, the LEAP Leaders grade student assignments and plan the weekly LEAP session based on their students' needs.

Figure 6: LEAP Session with 24 students and one LEAP Leader

The addition of the LEAP Program in the First-Year Engineering Program has benefits for the students, LEAP Leaders, and faculty. In a comparison study, students who had LEAP Leaders and LEAP sessions performed better on homework and exams than students with access to a course teaching assistant and no LEAP Sessions [2]. The students found their LEAP sessions to be helpful and that their LEAP Leaders displayed a personal interest in their learning, created an accepting atmosphere, and were positive role models [2]. The LEAP Leaders reported that the LEAP program helped them develop their communication skills, increased their confidence working in the group, leading discussions, and engaging a group of individuals on a task. In addition, the program helped them to set and articulate their personal goals, assess the quality of their own work, and deepen their understanding of core concepts [3].

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Engineering for All – High School Program

The Engineering 4 US All (e4usa) program is growing the K-12 pathway into engineering and STEM for all students through a collaborative program that supports high school teachers and students in a novel, 30-week curriculum in engineering principles, skills, and design processes. High school, colleges/universities, and industry/communities work together in partnerships to successfully implement the program. Teachers are trained to deliver this first-of-its-kind engineering course (with no prior knowledge required). Students are empowered to create change in their local communities by exposure to problems that are personally meaningful or associated with society's grand challenges, including sustainability, clean water, and human health. Students completing the program can receive college credit college/university partner institutions.

After four years of implementation, e4usa is now in 91 high schools in 25 states, DC and US territories. It has impacted over 5,000 high school students across the US. Demographics of the 2022-2023 cohort is approximately 37% underrepresented minorities and 43% women. Surveys of the first-year cohort of 82 students resulted in 52 out of 82 going into STEM degree programs.

Vertically Integrated Projects

For more info on VIP itself, the best source is here.

Here at Georgia Tech, we had 84 teams this semester and 1977 students registered. We will have at least 88 teams this Spring. 3 more are pending, so it may be 91. The current list of our teams is here.

Other useful inks:

VIP Consortium	VIP@NYU	VIP@Howard
VIP@GT	VIP@BoiseState	VIP@Arizona
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There are 48 VIP sites around the world, with at least one on every continent except Antarctica. The latest university to sign the Membership Agreement for the Consortium is the Univ of Auckland in New Zealand.

The Consortium holds the servicemark on "Vertically Integrated Projects" and the Consortium meets each year to plan research, help on-board new sites, share successes and challenges, update the list of essential elements of VIP, etc.

Overview

The Vertically Integrated Projects (VIP) model is a scalable, equitable and cost-effective high-impact experience that shows measurable gains in equity, professional skills, and job placement, with compensatory job-placement gains for marginalized students. VIP is an enhancement of undergraduate research, and it is a special case of project-based learning in which large, long-term multidisciplinary student teams are embedded in faculty projects. The model is adaptable, and it has been adopted at 48 institutions of varying types (large/small, public/private, research-intensive/teaching-focused, primarily-white/minority-serving) at varying levels (department, college, campus), with 28 programs in the US and 20 abroad [1]–[3]. This summary provides an overview of the model and key findings on impact.

The VIP Model

Through VIP, faculty embed large-scale, long-term student teams in their efforts in research, scholarship, design, and exploration. The model thus combines but also significantly enhances two high-impact experiences: undergraduate research and collaborative projects. Vertically integrated teams can occur organically when faculty mentor large numbers of students, but VIP Programs provide central structures that support access, equity, evaluation, and institutionalization of large-scale teams. The VIP Consortium identified 8 key elements of the model:

Projects are embedded in faculty mentor's scholarship and exploration. Full faculty engagement underlies the success of VIP. To sustain full engagement over many years, projects must be homed in and contribute to the faculty mentor's area(s) of interest.

Projects are long-term and large-scale, continuing for many years, even decades. VIP allows for larger-scale and longer-term projects than a single semester or year would permit. This allows faculty to take on more ambitious projects; it gives new students experience in getting up to speed on an existing project (as in the workplace); and it gives returning students leadership experience, as they help on-board new members, organize the team's work, and work with their adviser(s) to set the direction for the team.

The Program is curricular, and all participating students are graded (A-F; not P/F or S/U). VIP is not a club, it is a credit-bearing course that counts toward students' degree requirements. Letter grading holds students accountable for their work. In many ways, feedback and grading in VIP is like an evaluation in the workplace. Work is evaluated, guidance is given, and students have the opportunity to improve.

Students can participate and earn credits toward their degrees for at least two years. Long-term student involvement is the key to team success. When students join a team, they spend much of the first semester getting up to speed. They make their largest contributions in subsequent semesters, both in contributions to team expertise, mentoring of new students that join the team, and in team/idea leadership.

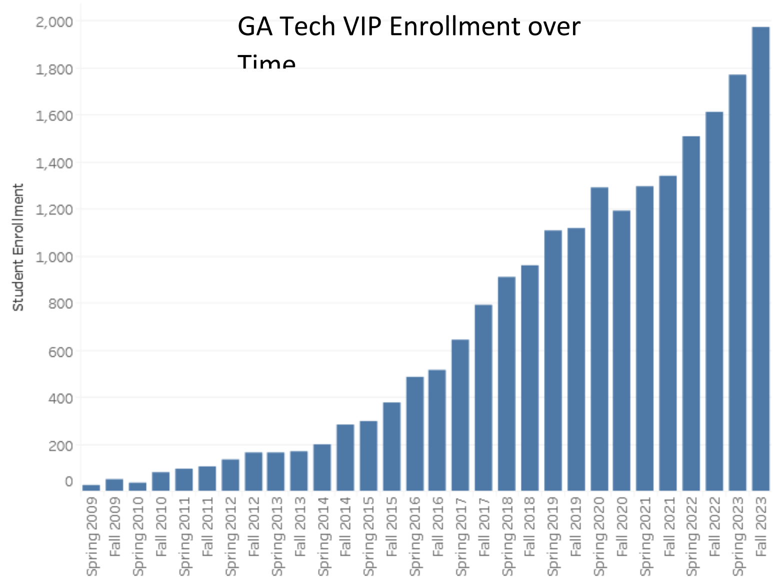
Learning outcomes focus on the development of both disciplinary and professional skills. VIP teams function like small start-up companies. While students develop and apply skills from their disciplines, they also develop and apply professional skills important to team functioning and highly valued by employers.

Multi-disciplinary teams are encouraged but not required. Multi-disciplinary teams have been a hallmark of VIP programs, giving faculty access via their VIP team to a variety of disciplines and skill sets. In some cases, a VIP site may be limited by departmental or curricular rules, which the consortium recognizes.

Dedicated classroom and meeting spaces. VIP teams differ from traditional classes, and it is important to provide spaces in which the teams can meet and work. Teams typically meet at the same time and day each semester, ensuring team meetings work well with instructors' schedules. Student access to the space outside of scheduled class times allows for sub-team meetings. Rooms are typically set up in conference room style to encourage collaboration.

Faculty/student participation is based on mutual interest. In VIP, students and faculty engage in projects that are of mutual interest, which is key to the success and scalability of VIP programs. Faculty stay actively engaged because teams help advance their scholarship and research and support the work of their graduate students. Students select projects that align with their personal interests. The single most influential factor that predicts student success on a VIP team is the student's enthusiasm for the project.

Scalable: Through VIP, **faculty can mentor many more students** than in traditional undergraduate research. Maintaining teams of 12-30+ students/team each semester ensures enough students return the following semester to maintain continuity. Returning students take on greater leadership and technical responsibilities each semester, which in turn enables faculty to lead such large teams. Because faculty benefit from their teams' work, VIP **cultivates long-term faculty engagement**. Projects evolve with faculty mentors' research, teams become incorporated into their research portfolios, and VIP can be used as broader impacts and educational components in proposals.



As an example of scalability, the Georgia Tech VIP Program was established with faculty from a handful of engineering and computing departments. The program now serves faculty from every college on the campus; it enrolled approximately 2,000 students in Fall 2023 (figure); and in the 2022-23 school year, approximately **1/3 of bachelor's degree recipients had participated** for at least one semester. Of all faculty who taught courses in Fall of 2023, only 3% were involved with VIP, which shows the **large impact a small number of faculty can have through VIP**. Further, faculty continue to request new VIP teams, enabling ongoing growth.

Cost Effective: The VIP model is cost effective because the program is curricular. Instead of paying stipends to students, students enroll in VIP as a course. The course is offered for 1 to 2 credits each semester, so students can participate for multiple semesters without exceeding the space available in their programs of study. Tuition collected for VIP credits has also driven the development of budget models that support VIP program operations and expansion [2]. The model is also cost-effective because teams are embedded in ongoing faculty research, leveraging existing resources.

Impact

Professional Skills: As stated in the key elements, the VIP model involves the development of both disciplinary and professional skills. In institution exit surveys, VIP participants more strongly agreed that their Georgia Tech educations contributed to their ability to **work in multidisciplinary teams**, ability to **work with people from diverse backgrounds**, and their **understanding of technologies** related to their disciplines (with meaningful effect sizes) [4]. Supporting these findings, social network analysis of peer evaluations found that within their VIP teams, students interacted more often with students from **other races/ethnicities**, and more often with students from **other majors** [5]. Analyses of peer evaluations also **showed leadership growth** with multiple semesters of participation and no correlation with academic rank, confirming that returning students take on leadership roles within their teams [6], [7].

Job Placement: Analysis of Georgia Tech career and salary surveys showed that across the institution, historically underserved minority (URM) students and Asian students had 6% lower job-placement rates than white students. In contrast, VIP participants reported **6% higher job-placement rates** than non-participants, with **9% gains among URM and Asian students and equity by race/ethnicity** among participants [8]. While the underlying mechanisms are still being studied, this mirrors compensatory gains seen among marginalized students who participate in multiple high-impact experiences [9].

Equity: Nationally, URM students, first-generation students and transfer students participate in undergraduate research at lower rates than their peers [10]. An analysis of VIP enrollment across five institutions showed **equity or near-equity for all three demographics** [11]. Additionally, analysis of enrollment at Georgia Tech showed that students returned for second, third and subsequent semesters of participation at the same rate, regardless of race/ethnicity, an additional level of equity [12]

The VIP Consortium

Established in 2014 through a grant from The Helmsley Charitable Trust, the VIP Consortium provides a peer-network for VIP Directors. *As funding permits, The Consortium holds an annual meeting through which directors learn from each other, share best practices, and collaborate on continued improvement and dissemination of the VIP model.*

Recommendations

If the National Science Foundation funded the establishment of VIP Programs and VIP supplements, as they support establishment of NSF REU Sites and REU supplements, substantially more students could be engaged in team-based undergraduate research. Additionally, with NSF support, the VIP Consortium could provide professional development and mentoring to a larger number of institutions, enabling wider-spread adoption of a successful and equitable model.

References

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Webpages

VIP Consortium - https://www.vip-consortium.org/

GA Tech VIP Program - https://vip.gatech.edu/

NYU Tandon School of Engineering VIP Program - https://engineering.nyu.edu/research-innovation/student-research/vertically-integrated-projects

Boise State University VIP Program - https://www.boisestate.edu/vip/

Howard University VIP Program (HBCU) - https://www.mwftr.com/VIPatHUteams.html

University of Hawaii VIP Program (Native Hawaiian-serving institution) - https://manoa.hawaii.edu/uh-vip/

University of Arizona VIP Program (Hispanic-serving institution) - https://uavip.arizona.edu/