The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #44109

Work in Progress: Reimagining the ECE Curriculum: Bridging Technical Preparation, Professional Formation, and University Mission for a Holistic Education

Dr. Shiny Abraham, Seattle University

Dr. Shiny Abraham is an Associate Professor of Electrical and Computer Engineering (ECE) at Seattle University. Her disciplinary research efforts focus on the application of Internet of Things (IoT) technology and Machine Learning towards remote environmental monitoring, and soil and water conservation. Her pedagogical research revolves around leveraging technology trends to enhance interest in ECE, as well as broadening participation in engineering. Dr. Abraham is a member of the IEEE and ASEE, and she serves in leadership roles within both organizations. She also serves on the board of the Inclusive Engineering Consortium (IEC). Dr. Abraham received the B.E. degree in Telecommunication Engineering from Visveswaraiah Technological University (VTU), India in 2007 and Ph.D. from Old Dominion University, Norfolk, VA in 2012.

Dr. Mehmet Vurkac, Seattle University

Mehmet Vurkac is an assistant professor in the Department of Electrical and Computer Engineering at Seattle University.

Dr. Agnieszka Miguel, Seattle University

Dr. Miguel is Professor and Department Chair of Electrical and Computer Engineering at Seattle University. Dr. Miguel received her Ph.D. in Electrical Engineering from the University of Washington, and MSEE and BSEE from Florida Atlantic University. Her professional interests involve image processing, machine learning, and diversity, equity, and inclusion in engineering education. Dr. Miguel held several ASEE officer positions including Vice President for External Relations, First Vice President, and Vice President of Professional Interest Councils. She was a member of the ASEE Board of Directors from 2016 until 2023. She was the President of the Electrical and Computer Engineering Department Heads Association (ECEDHA) in 2022-2023 and was the Program Chair of the 2022 ECEDHA Annual Conference.

Dr. Margarita D. Takach, Seattle University

Dr. Margarita Takach is an Associate Professor in the Electrical and Computer Engineering Department at Seattle University. She earned her PhD degree from the University of Washington. Her teaching interests include digital and analog circuits and systems, and signal processing.

Eddy Ferré, Seattle University
Shruti Singh, Seattle University

Dr. Shruti Singh is a Term Faculty in the Electrical and Computer Engineering Department at Seattle University. She earned her PhD degree from University of Denver specializing in renewable energy and smart grids. Her research focus is on renewable energy integration into smart grids, ensuring efficient energy management and grid stability, aiming for a sustainable impact. She is a member of IEEE, ASEE and SWE and has worked on several NSF and NREL funded projects.

Prof. Henry Louie, Seattle University

Dr. Henry Louie received the B.S.E.E. degree from Kettering University, the M.S. degree from the University of Illinois at Urbana-Champaign and the PhD degree in Electrical Engineering from the University of Washington in 2008. He is currently an Associat

Work in Progress: Reimagining the ECE Curriculum: Bridging Technical Preparation, Professional Formation, and University Mission for a Holistic Education

Abstract

The changing landscape of engineering education is driven by the need to prepare and graduate engineers who can tackle global challenges and pioneer technological advancements in an ethical, sustainable, and equitable way. This calls for pedagogical innovations, a shift in the curriculum, and a broader and more holistic skillset than is traditionally taught in most engineering programs. While technical proficiency is crucial, the development of professional formation skills and an understanding of the interconnectedness of global issues are equally vital.

In response to Seattle University's call for a bold and comprehensive reimagining of curricula campus-wide, the ECE department has embarked on a transformative journey that bridges professional formation and technical preparation in a mission-aligned manner. Revised curricula will include

- Themes such as sustainability and climate change, racial and economic justice, technology and its impacts on society, community engagement and experiential learning, and universal design.
- Elements of professional formation such as ethical and cultural awareness, emotional intelligence, leadership and communication, and continual learning, among many others.

The authors envision that this paper will be the first in a series of papers that document the process of integrating professional formation and the university's mission into the ECE curriculum at Seattle University. This paper will focus on reimagining the curriculum, while future papers will focus on revising, implementing, and evaluating the proposed changes. Over the course of this work, curriculum-mapping tool and curricular-auditing tools custom-designed for the aforementioned themes will be used to align the proposed themes and skills with course-specific learning outcomes.

Motivation

The landscape of higher education in the United States is changing. The value of a college degree and the resulting employment opportunities are under the scrutiny of the general public **[1]**. Higher education is perceived as valuable but unaffordable. There are calls for accountability and transparency regarding graduation and employment rates **[2] [3]**. At the same time, according to Kodey et. al., "Every year, the US will need about 400,000 new engineers. Yet the next-generation skill sets that those engineers will require are sorely lacking, presenting the alarming possibility that nearly one in three engineering roles will remain unfilled each year through at least 2030" **[4]**.

The demand for electrical and computer engineering graduates continues to grow. According to the U.S. Bureau of Labor Statistics, employment for both electrical and computer engineers is projected to grow by 5% from 2022 to 2032, which is faster than average for all occupations **[5] [6]**. However, the expectations of the skills that they would bring into their workspace are potentially misaligned with what typical engineering programs are able or willing to teach. A 2020 ASEE Corporate Member Council (CMC) survey of 350 recent engineering graduates investigated the gap in technical and professional skills acquired from education and needed in the workplace **[7]**. In this context, professional skills are defined as "skills essential to thrive in a work setting but not historically included in engineering or engineering technology coursework." The nine professional skills surveyed were: communication skills, emotional intelligence, teamwork and multidisciplinary work, curiosity and a persistent desire for continuous learning, project management, critical thinking, self-drive and motivation, cultural awareness in a broad sense, high ethical standards, integrity, and global, social, intellectual and technological responsibility. Results showed that nearly 59 percent of respondents felt unprepared in management and business skills, 60 percent in ethical standards, integrity and responsibility, and 63 percent in critical thinking. The National Science Foundation (NSF) and ASEE's *Transforming Undergraduate Engineering Education Phase II; Insights from Tomorrow's Engineers* (TUEE) survey, conducted in 2015 **[8]**, showed comparable results.

While professional skills typically refer to specific competencies or abilities that individuals develop, professional formation encompasses the holistic development of individuals as professionals. Formation occurs over time and denotes "a way of being and acting in practice and in the world" **[9]**. Professional formation focuses on who the learner becomes more than what the learner knows. Culture and context play an important role in professional formation, encompassing educational, workplace, ethical, and social dimensions within which individuals develop their identities as professionals. The prevailing perception of engineering tends to focus solely on technical aspects and lacks a human-centered and holistic approach **[10]**. The socio-technical nature of the 14 Grand Challenges identified by the U.S. National Academy of Engineering (NAE) acknowledges the interconnectedness of technical systems and social contexts **[11]**. Research shows that embracing a broader perspective of engineering identity provides a wider range of experiences that diverse individuals can relate to, fostering a sense of inclusion and belonging among participants **[12] [13]**.

This paper documents our work of reimagining the undergraduate ECE curriculum at Seattle University by bridging professional formation and technical preparation, in alignment with the strategic directions of the university. The proposed curriculum-change efforts bring us one step closer to providing a holistic engineering education to our students, preparing them to take on the most complex technological, social, environmental, and economic challenges of the 21^{st} century. The authors recognize that implementing these changes necessitates a cultural shift from traditional engineering education that often prioritizes technical knowledge above all else to a holistic approach that infuses professional skills, sustainability, ethical awareness, and societal impact considerations in the curriculum **[14]**. We aim to challenge the perceived dichotomy between technical and professional skills by graduating students who are technically proficient engineers but also ethical, socially responsible, and adaptable professionals capable of addressing the grand challenges of today's world. As we progress through the stages of this work, we expect that our experiences can serve as a beacon for other institutions, especially for attracting and retaining a diverse student body whom we nurture in their path to becoming whole-person engineers.

The Work We Are Doing

In doing this work, we recognize—and indeed share —concerns about compromising the technical preparation of our graduates.

Even with curricula that are full to the brim with technical topics, we, like most engineering faculty, bemoan the amount of further technical material we wish we could present to our students. Hence, we acknowledge that to infuse an ambitious array of knowledge and skills related to sustainability and social justice as well as habits of mind like emotional intelligence, critical thinking, universal design, and cultural humility into the curriculum could seem naïve or even harmful.

However, when we consider the evolution of engineering education over the long and the short term, we find that what is most critical for educators to impart has always shifted with the development of technology and its scientific and mathematical toolboxes. In electrical and computer engineering, there is much more technical content that was once taught in four-year programs, which we have since dropped, than there is technical material taught anywhere today.

For instance, depending on the focus of a program and the industries prevalent in its geographical area, topics like assembly language, vacuum tubes, BiCMOS circuit design, or the distinctions of enhancement- and depletion-mode transistors, each of which was once considered critical, may not be taught at all in undergraduate programs today. Likewise, skills such as coding backpropagation, random initialization, and cross-validation from scratch, once routine in teaching machine learning, would be seen quaintly out of touch with professional practice today.

Looking further back in history, the construction and operation of inductors and capacitors, once an area of innovation, now commands on the order of two or three class periods in introductory circuits courses. In today's circumstances, it would more often than not be a disservice to our *undergraduate* students to demand they write machine code to access registers, learn to design with tube amplifiers, wind all their own inductors, or reinvent the wheel for common operations in *scikit-learn*, *pandas*, or *OpenCV*. All these skills are still relevant for certain professional roles or applications, but the modern undergraduate curriculum prioritizes learning how to learn and becoming a resourceful problem-solver over accumulating the maximal set of discrete technical skills. If the latter were the case, becoming an electronics engineer would entail little more than memorizing Horowitz and Hill's *The Art of Electronics*. Instead, today's critical technical knowledge is the type of social understanding that will help future engineers avoid catastrophes like the recent Boeing accidents **[15] [16]** that cost hundreds of lives and scandals like Google's many AI blunders **[17] [18]**.

We have also considered the trade-offs between creating a single class on professional formation where we could concentrate on these seemingly non-technical topics. While being aware that in some cases, infusing material throughout the courses making up a degree program can lead to that material being left out due to not having a single point of contact—everyone trusts that everyone else is doing it and that they could leave out their part just for once, after which the auxiliary material gets elbowed out to address new technical developments, external pressures, and so forth. We are, however, conscientious about both the reason to spread this work out and the how to sustain it.

For the former, as faculty who advise all the students in our programs—with each of whom we meet no less than three times each year (no less than once per quarter, typically two or three times) just for advising—we are familiar with many students' tendency to identify what they consider throw-away courses. These are required courses that many students do not perceive as essential to their career. And because we cannot teach our major courses more than once per year, it is sometimes justifiable for a student to leave these auxiliary-seeming courses (typically writing, economics, or ethics) until late into their senioritis. Our goal with these professional-formation skills is to get students to internalize them as true job skills and career skills, not to mention life skills. In today's economy, we cannot blame students or parents if they do not focus beyond getting that first STEM job right after graduation. We make sure it remains part of our focus for our students to be empowered to keep that first job, move up in that job, find better-suited jobs in the future, and serve humanity as ethical multifaceted engineers and civic-minded justice-oriented informed citizens.

Consequently, our plan to sustain this effort has two pillars. One is to integrate professional formation with technical material, pulling case studies and applications directly from the technical topics that each class addresses. We have already located[1] case studies and applications for some of the more challenging skills on our list (see the appendices) such as the environmental advantages of technology (and its harms), the effects racism has had on the United States' patent competitiveness and sexism on the UK's loss of computational leadership, the conditions of child slave labor to meet the demand for various natural resources used in high- and medium-tech products, and opportunities for practicing critical thinking, debate skills, and cultural safety.

The other pillar of our sustainability plan is that we have synchronized the placement of career-oriented skills into the curricula with our regular annual career-oriented departmental co-curricular events. And since these are under our direct control, the synchronization is not likely to be broken without the knowledge of the departmental faculty.

Thus, we believe we have set ourselves up to maintain this strategic reimagining of our EE and CMPE programs. This is because (1) professional formation is not relegated to a single course that could be discontinued under budgetary pressures or mostly avoided by some students, and (2) because it is not a loose suggestion that a few junior faculty handle some added material, but a careful plan that comes with ready-to-teach modules on relevant technical topics—owned by all, reflected in each set of our course outcomes, and posted on the department's front page on the Web. This is a plan we see as our new departmental identity and one that will enable us to weather the demographic cliff and other big challenges facing academia in the United States.

University-level RRC Curriculum Priorities

Seattle University launched a multi-year effort to comprehensively reimagine and revise curriculum with a call to integrate practices that would make the education we offer distinctly unique and relevant to global challenges. *Reimagine and Revise the Curriculum* (RRC) was envisioned to be an initiative that is led by faculty within their own undergraduate and graduate programs and departments, with programmatic support offered at the university level through

[1] from sources such as the IEEE *Spectrum*, the National Academies, the US Geological Survey, major daily national newspapers, science and technology journals, nonfiction popular books on technology and technology ethics, and textbooks on engineering ethics.

various avenues. This framework allows for discipline-specific approaches to embedding the RRC goals into our curricula. RRC was designed to be a multi-phased, multi-layered, and comprehensive curriculum-change effort that is divided into four phases:

Phase 0—Launch: An overview of the RRC plan and timeline was shared with the campus community. University leaders, faculty, and other stakeholders engaged with Provost Fellows—faculty who have been selected to constitute working groups related to the five curricular priority areas listed below.

1. Sustainability and Climate Change
2. Racial Injustice and Widening Economic Inequity
3. Technological Change and its Impact on Society
4. Community-Engaged Learning
5. Ignatian Pedagogy, Experiential Learning, and Universal Design

Phase 1—Reimagine: Departments were called upon to examine their existing discipline-specific curricular outcomes and reimagine them around the multiple prongs of RRC. Outcomes are statements about what we prepare our students to be able to write, say, think, and do (and even be) by the end of their course of study. In reimagining what each program wants for students they graduate, the following ways were suggested for the revision of outcomes.

- Tweak an outcome to enlarge the thematic area it addresses.
- Tilt an outcome toward one of the RRC curricular priorities.
- Boost a specific curricular priority in one of the outcomes.
- Create a new curricular outcome.

At the end of this phase, we generated an inventory of professional-formation skills, grouped them into program curricular outcomes (PCOs), and mapped them to RRC Curricular Priorities, shown in **Figure 1** that illustrates a high-level overview of the themes.

Phase 2—Revise: We are currently in this phase, developing and making decisions on the curricular revisions that were reimagined in Phase 1. Department-level RRC coordinators have been engaging with Provost Fellows and their department colleagues to facilitate the revision process. As part of this phase, our department has identified courses in which an outcome or multiple outcomes would be revised to address one or more RRC curricular priority areas as shown in the roadmap presented in **Figure 2**. The key to course numbering is provided below the figure in *Table 1*.

Phase 3—Implement: Departments are to submit curriculum proposals for review and approval.

Department-level Professional Formation

The ECE department at Seattle University offers two programs, BS in Electrical Engineering and BS in Computer Engineering. The corresponding program curricula provide adequate content that prepares graduates in the attainment of ABET student outcomes (1)–(7): problem-solving, engineering design, communication, professional responsibility, teamwork, experimentation, and

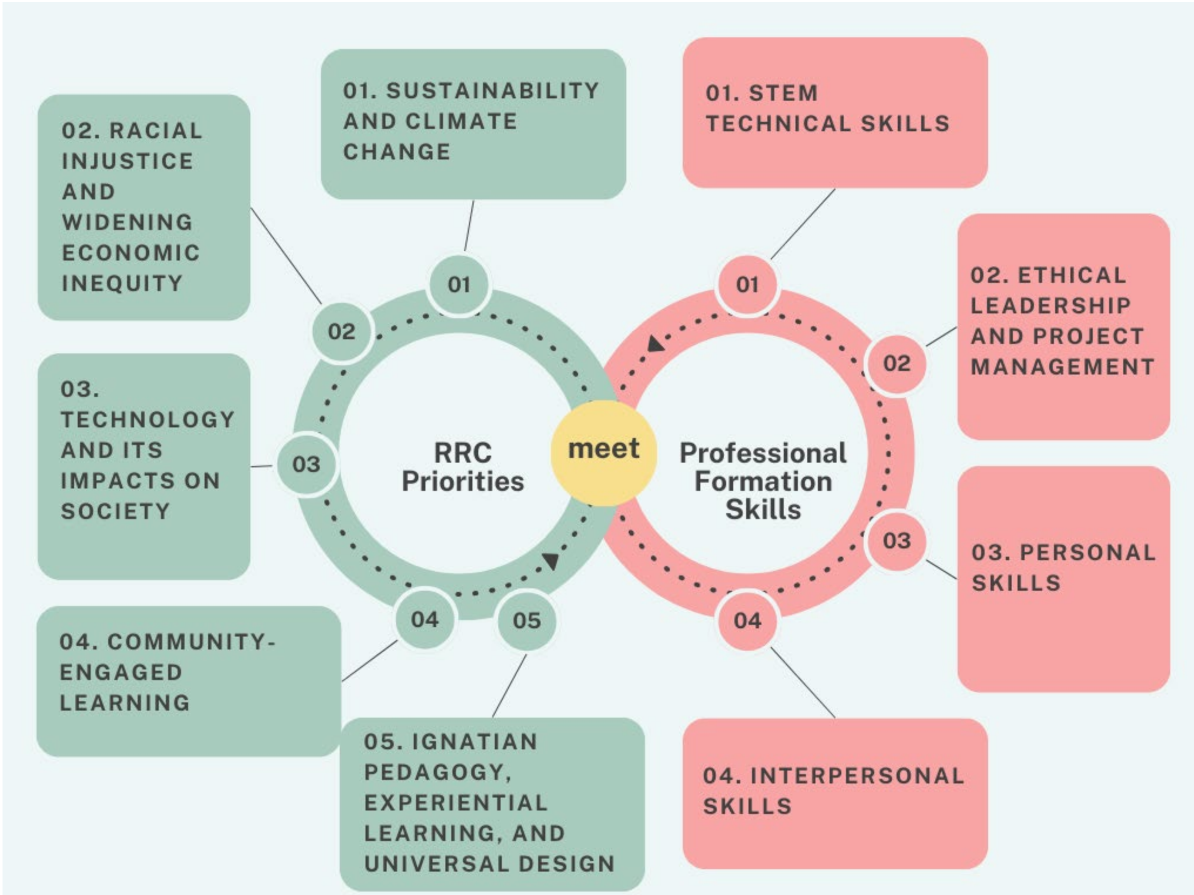

Figure 1: Interconnectedness of RRC Curricular Priorities and Professional Formation Skills

learning. While ABET emphasizes both technical preparation and professional formation, our response to the university's call for the need to educate in a more cohesive, powerful and mission-aligned way has prompted the creation of aspirational program outcomes that supplement the existing ABET student outcomes. Our *program curricular outcomes* (PCOs) encompass a broader and more holistic skillset than is traditionally taught in engineering programs. In consultation with the ECE Advisory Board (ECEAB) at Seattle University, our department has identified four broad categories of skills for professional formation that we would like our students to acquire by the time they graduate, as illustrated in **Figure 3**.

1) *STEM Technical Skills* – Graduates will demonstrate advanced proficiency in STEM-related technical skills, encompassing computational thinking, data analysis, scientific inquiry, engineering design, technology utilization, and other skills essential for innovation and problem-solving in diverse professional settings.

2) *Ethical Leadership and Project Management* – Graduates will demonstrate ethical leadership, proficient project-management skills, and a commitment to racial justice and sustainability, empowering them to navigate diverse challenges with integrity while fostering inclusive practices and environmentally conscious solutions.

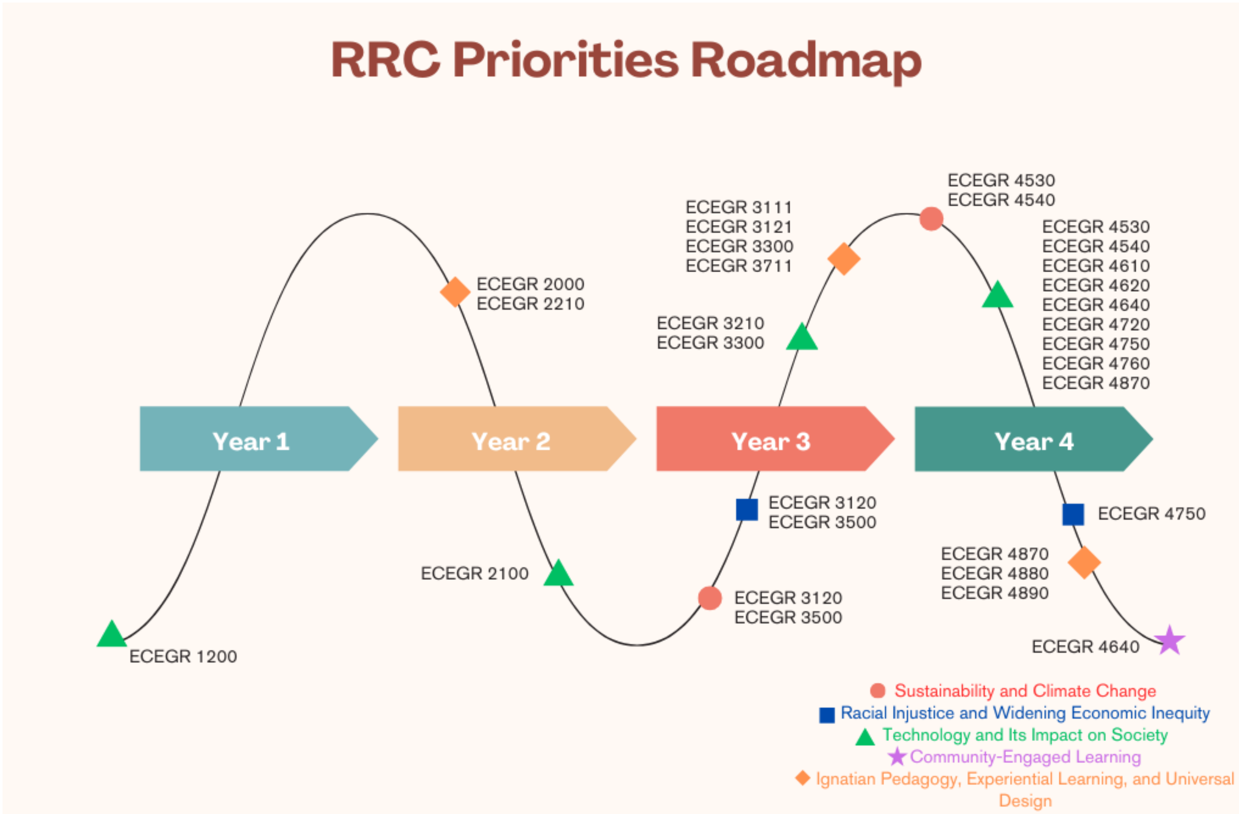

Figure 2: Roadmap of RRC Curricular Priorities integrated within the undergraduate ECE curriculum at Seattle University[2]

Table 1: Key to course numbering by level, subdiscipline, lecture/lab, and place in sequence

ECEGR WXYZ Course Numbering	
Code W	1 – First Year; 2 – Second Year; 3 – Third Year; 4 – Fourth Year
Code X	0 – programming and software; 1 – analog circuits and electronics; 2 – digital electronics; 3 – electromagnetics; 4 – control systems; 5 – power systems; 6 – communications; 7 - signals (including machine learning); 8 – yearlong design project; 9 – independent study
Code Y	Order in sequence of lectures
Code Z	Order in sequence of labs

3) *Personal Skills* – Graduates will have developed a comprehensive set of personal skills encompassing executive function, critical thinking, adaptability, and emotional intelligence, empowering them for success in both personal and professional contexts.

4) *Interpersonal Skills* – Graduates will have developed a diverse range of interpersonal skills, including effective communication, teamwork, conflict resolution, and empathy, fostering their ability to collaborate harmoniously and thrive in various personal and professional environments.

[2] The choice of a sinusoidal form for the roadmap is simply to fit more information into a smaller figure and does not convey hierarchy among the courses or RRC priorities.

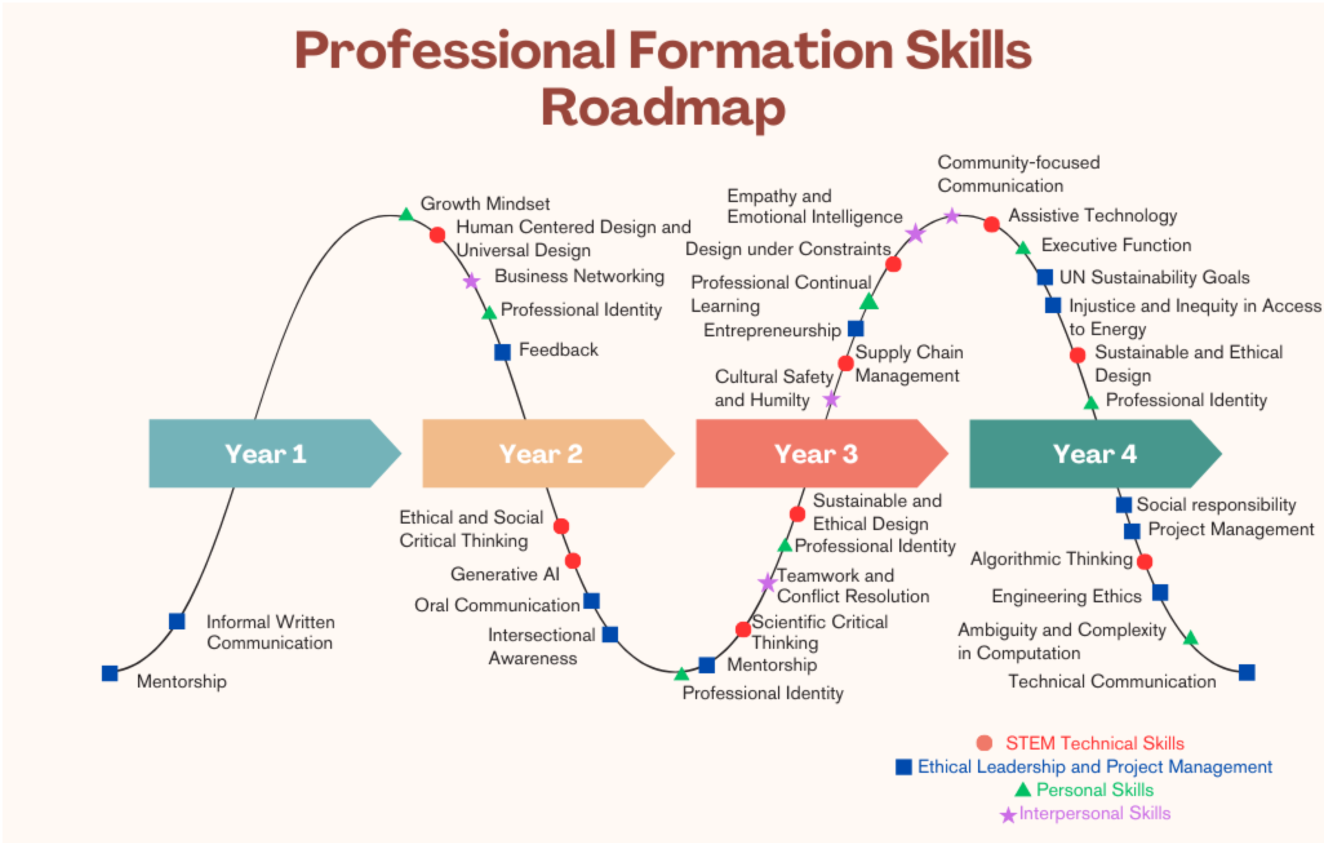

Figure 3: Roadmap of program curricular outcomes integrated within the undergraduate ECE curriculum at Seattle University

Linking the University's Priorities to the ECE Skills for Professional Formation

We have taken on a gargantuan yet very important task. In bringing our two curricula up to the standards of the university's new vision, we are also working to enable our students to enter the workforce as significantly better-rounded individuals than we did before. We are in a position to expose our students to a broader understanding of how technical fields do not exist in a STEM vacuum, but that they both generate and face consequences of a societal, economic, and ecological nature. We are encouraged by the university's commitment to expanding students' engagement with such critical dimensions of the work of engineering to racially, geographically, economically, and otherwise underrepresented—even ignored—stakeholders.

In preparing for this work and subsequently in our department-wide discussions and work sessions, we have deepened our understanding of the ways in which technology, business, science, and engineering interact bidirectionally with diverse populations in their contexts and circumstances.

The first stage of the work was to identify the low-level skills that graduates in electrical engineering and computer engineering ought to have. These include skills that we have been imparting and those we have not addressed yet. They include specific technical skills for each program and general (personal and interpersonal) skills for building and maintaining any career. They also include further personal and interpersonal skills for being good citizens and for interacting justly, insightfully, and productively with all other individuals, stakeholders, teams, systems, and populations. A small sampling at maximum granularity of these skills across the spectrum of goals and outcomes follows, with the complete list presented in the appendices.

- Sustainable and ethical design as informed by the energy budget and carbon footprint of technology and commerce
- Sustainable and ethical design as informed by rare and dangerous materials, colonialism, extractivism, mining, and human rights
- Interdisciplinary design at the electronic–mechanical interface
- Experience using open-source software
- Scientific critical thinking
- Ethical and social critical thinking
- Knowledge of UN sustainability goals and grand challenges
- Awareness of injustice and inequity as part of ethical leadership (in access to energy, food security, public health, entrepreneurship, etc.)
- Being able to successfully address disabilities and access needs in devising and running technical demonstrations
- Resilience, tenacity, failing forward, and building confidence
- Emotional intelligence
- Active listening

We developed this structure as an attempt at having a complete inventory of professional-formation skills, but also to help us map the five RRC priorities to our four program curricular outcomes (PCO).

In our early mappings, we observed that we were thinking overly broadly. It is possible to link each RRC priority to almost every PCO. Such a mapping is trivial and uninformative. Fortunately, the practical concern of keeping the professional-skills roadmap in congruence with our assessment cycle and our co-curricular activities (such as networking and résumé-review events with industry professionals) imposes some restrictions on where in the curricula we can place various professional skills. We have been finding it challenging but enjoyable to stay true to the spirit of the RRC goals in finding the best-suited components of professional formation for each stage in the curricula.

At this point, the reader may want to know how these skills are to be addressed. We do not expect STEM faculty to be sufficiently knowledgeable about racial justice, the economy, the societal impacts of specific technologies on the Global South, or even every aspect of working with open-source software or databases, not to mention résumés, elevator pitches, or entrepreneurship. In a small number of cases, some of the departmental faculty have volunteered to develop modules and lesson plans, but for the most part we plan to rely on three sources of content: (1) modules we can acquire from experts and reuse, (2) faculty from other departments throughout the university who can visit a certain class once per term or once per year to deliver a module in their area of expertise and for which they get some form of workload credit or stipend, and (3) professionals from some of the many innovative technology companies, large and small, in our city, primarily members of our departmental advisory board (ECEAB).

Another point of doubt may be how, even whether, the broad RRC goals can be related to specific technical skills. Evidence of the interrelatedness of all these skills emerged from our process of developing the tree structure of skills: Branches that appear to be unrelated, such as testing and troubleshooting, turned out to fall under the same PCO as the geopolitics of materials. As another example, agile development appeared in the same *broad* category as journal literacy, inequity in health-care access, and whistleblowing.

In addition to the work of infusing professional formation into the EE and CMPE curricula, we are developing other ways to reinforce our students' continued engagement with these ideas. These include developing a minor in humanitarian engineering (in collaboration with the departments of Civil Engineering and Mechanical Engineering) including courses on topics like off-grid electrification in the Global South. The course learning outcomes are to be able to (1) define and articulate energy poverty and its influence on human development, understand the principles of operation of common off-grid electrification components, model off-grid electrical systems, design appropriate off-grid electrical systems, and describe best practices of off-grid system implementation and operation considering technical and non-technical factors.

In summary, although work is still in progress, we have mapped several specific skills to common points along the curricula (as seen in **Figure 3**), to the RRC priorities, and to ABET student outcomes as part of our department-wide initiative to make students' exposure to and understanding of the RRC goals—and how intertwined they are with the profession of electrical and computer engineering —an integral part of their engineering education. Our goal is for students to never doubt that *all* of these skills are crucial to their formation as excellent 21st-century engineers. This work is also providing authentic assessment opportunities for ABET student outcomes.

Future Work

In Phase 3, learning outcomes for individual courses will be revised and approved at the department level. Modules that address either an RRC curricular priority, a PCO-related skill, or a combination of the two will be created. This will be done in collaboration with the ECE Advisory Board, faculty colleagues from across the university, and subject-matter experts. We will use senior exit surveys, one of our ABET continuous improvement assessment tools, to get student feedback on the department's success in bridging the skills gap. For each of the RRC themes and PCO-related skills, survey respondents will be asked to rate their level of preparedness on a scale of *very prepared* to *not prepared at all*. Survey responses will be monitored over time to assess the impact of these changes and identify areas where further intervention may be needed. Survey feedback will be used to iteratively refine the modules and course learning outcomes.

Appendix A: Seattle University ECE Themes of Professional Formation

1. STEM Technical Skills (Scientific, Engineering, and Computational Skills)
    a. Design Skills
        i. Engineering Trade-offs and Design under Constraint
            1. Global, Cultural, Social, Environmental, and Economic Constraints
            2. Concern for Public Health, Safety, and Welfare
        ii. Sustainable and Ethical Design Practices
            1. Design Informed by the Energy Budget and Carbon Footprint of Technology and Commerce[3]
            2. Design Informed by Rare and Dangerous Materials used in Technology
                a. In Terms of the Environment
                    i. Planned Obsolescence and Inaccessible Design
                    ii. Recycling: Pros and Cons
                    iii. Technology and Runaway Consumerism
                    iv. The Environmental Advantages of Technology
                b. In Terms of Colonialism, Extractivism, Mining, and Human Rights
                c. In Terms of the Geopolitics of Materials
        iii. (Dis)ability, Access, and Human-Centered & Universal Design
        iv. Iterative Design
        v. UX Design
        vi. Interdisciplinary Design
            1. Design at the Analog–Digital Interface
            2. Design at the Hardware–Software Interface
            3. Design at the Electronic–Mechanical Interface
        vii. Testing and Troubleshooting
    b. IT Skills
        i. Facility with Conventional and Cloud-based Tools
            1. Facility with Office-Productivity Tools
            2. Facility with EDA Tools
            3. Facility with Scientific and Computational Tools
        ii. Facility with Proprietary or Specialized Tools
        iii. IT Troubleshooting
    c. Computational Skills
        i. Algorithmic Thinking
        ii. Working with Data Structures
        iii. Database Literacy
        iv. Experience with Open-Source Software
            1. Using
            2. Developing
        v. Generative AI

[3] deep learning and foundation models (large language models, etc.), the blockchain, manufacturing, global commerce and the supply chain, rampant consumerism, etc.

1. Prompting Skills
2. Technical Knowledge
3. Ethical Issues and Pitfalls
4. Fairness, Explainability, Interpretability, Transparency, Justifiability, Contestability, Trustworthiness, Transferability, Informativeness, Stability, Robustness, Actionability, and Usability (User Focus) of Models [19] [20] [21] [22] [23]
5. Fairness, Accessibility, Assessibility, Trustworthiness, Robustness, and Anonymization of Datasets [19] [20] [21] [22] [23]

d. Critical-Thinking Skills
   i. Cognitive Critical Thinking (including knowledge of such biases, fallacies, and heuristics as absence of evidence, anchoring heuristic, appeal to ignorance, argument from authority, base-rate fallacy, Bayesian risk, chance and coincidence, availability heuristic, confirmation bias, conjunction fallacy, directional thinking, Dunning–Kruger effect, framing effects, gambler's fallacy, groupthink, halo effect, loss aversion, misattribution, claim–evidence-strength mismatch, pareidolia, parsimony, planning fallacy, , *post hoc* fallacy, publication bias, regression to the mean, representativeness heuristic, selection bias, selectivity of perception, sharp-shooter fallacy, stereotyping, storehouse view, weasel words, etc.)
   ii. Scientific Critical Thinking
      1. Accuracy[4]
      2. Precision
      3. Skepticism[5]
      4. Open-mindedness[6]
   iii. Ethical & Social Critical Thinking
      1. Awareness of Implicit Biases
      2. Diversity Literacy
      3. Equity Literacy
      4. Injustice Awareness

2. Ethical Leadership and Project Management
   a. Knowledge of UN Sustainability Goals and Grand Challenges
   b. Agile and Other Team-based Development
   c. Feedback
      i. Receiving Feedback as a Leader
      ii. Providing Feedback as a Leader
   d. Intersectional Awareness
      i. Injustice and Inequity in Access to Energy
      ii. Injustice and Inequity in Food Security & Public Health
      iii. Injustice and Inequity in Healthcare Access
      iv. Injustice and Inequity in Education Access

---

[4] aiming to collect data and design experiments as free from bias as possible [26]
[5] being prepared to challenge ideas, even if they come from people or places of authority (Ibid.)
[6] willingness to give up one's strongly held views in the face of strong evidence to the contrary (Ibid.)

v. Injustice and Inequity in Hiring & Promotion
vi. Injustice and Inequity in Entrepreneurship

e. Mentorship
   i. Mentoring
   ii. Peer Mentoring
   iii. Mutual and Cross-Mentoring
f. How Research Works
   i. Journal Literacy
   ii. How to Use IEEE *Xplorer*
   iii. "What is a conference?"
   iv. "What is an abstract?"
   v. "What is a research paper?"
g. Project-Management Skills
   i. Meeting Management
   ii. Supervising
   iii. Planning
   iv. Scheduling
   v. Budgeting
h. Supply-Chain Management
i. Contracts
j. Communication
   i. Formal Written Communication
      1. Technical Writing
      2. Business Writing
   ii. Informal Written Communication
   iii. Oral Communication (including the "Elevator Pitch")
   iv. Designing and Making Presentations
      1. Visualization
      2. Disability and Access
   v. Devising and Running Technical Demonstrations
   vi. Debate and the Ability to Be Part of a Discussion
k. Strategic Skills
   i. Entrepreneurship
   ii. Strategic Thinking
   iii. Ethical Leadership
      1. Leadership Humility
      2. The Triple Bottom Line and Other Alternative Paradigms
   iv. Risk Management
l. Whistleblowing

3. Personal Skills
   a. Professional Identity
      i. Web Presence
      ii. Online Portfolio

            1. *Git*, *GitHub*, *GitLab*
            2. *Hugging Face*, *Kaggle*
            3. *Colab*, *Jupyter*/*JupyterLab*/*conda*/*Anaconda*
            4. *LinkedIn*
        iii. Résumé, Thank-You-Letter, and Cover-Letter Writing
        iv. Interviewing Skills
    b. Professional Continual Learning
        i. On-the-Job Continual Learning
        ii. the *Fundamentals of Engineering* Exam
        iii. Master's Degree
        iv. Ph.D. Degree
        v. Certificates
    c. Resilience, Tenacity, Failing Forward, and Building Confidence
    d. Ability to Deal with Ambiguity and Complexity
    e. Ownership and Accountability
    f. Initiative (Being Proactive)
    g. Curiosity and Motivation
    h. Creativity and Innovation
    i. Growth Mindset
    j. Executive Function
        i. Organization
        ii. Prioritization
        iii. Time Management
        iv. Emotional Regulation
    k. Continual Self-Development
    l. Grit[7]
4. Interpersonal Skills
    a. Decision-Making
    b. Problem-Solving
    c. Mentoring
    d. Networking
    e. Etiquette
    f. Negotiation
    g. Cultural Safety[8]

---

[7] There is a potential for clash with disabilities here.

[8] Here are some descriptions of cultural safety taken from the article [24] and its references. "The focus is on the culture of the [engineer] and the [technological-development] environment rather than the culture of the 'exotic other' [stakeholders or community]." And the elements of cultural safety are as follows.

- acknowledging the barriers arising from inherent power imbalances;
- sharing decision-making with affected communities;
- turning focus back toward power, marginalization, and potential bias in the practitioner's perception and cognition;

h. Cultural Humility
i. Empathy
j. Emotional Intelligence
k. Recognizing & Rewarding
l. Conflict Resolution
m. Teamwork
    i. Active Listening
    ii. Division of Labor
    iii. Overlapping Roles and Supporting Team Members
    iv. Flexibility in Teamwork
    v. Decision-Making
n. Community-focused Communication
    i. Community Building and Community Stewardship
    ii. Supporting and Sustaining Communities
    iii. Communicating with Communities
        1. Listening to Community Members
            a. In-person Interactions
            b. Dynamic Online Communication
            c. Hybrid Interactions
        2. Presenting Information to Communities
            a. In-Community Presentations
            b. Static Online Communication
            c. Hybrid Interactions
    iv. Communicating as Part of Communities
        1. Written Advocacy
        2. Oral Advocacy
        3. Nurturing Community

- being prepared to interrogate or critique power, privilege, and racism, and to promote social justice;
- avoiding blaming the victim (such as in cultural-deficit theories);
- rejecting cultural essentialism ("Black people dance well." "All Asians are good at math.");
- examining sources of repression, social domination, and structural variables such as class and power; practicing critical self-reflection, i.e., "stepping back to understand one's own assumptions, biases, and values, and a shifting of one's gaze from self to others and conditions of injustice in the world." [25]

Appendix B: Simple List of Our Themes of Professional Formation

Global, Cultural, Social, Environmental, and Economic Constraints

Concern for Public Health, Safety, and Welfare

Design Informed by the Energy Budget and Carbon Footprint of Technology and Commerce[9]

Planned Obsolescence and Inaccessible Design

Recycling: Pros and Cons

Technology and Runaway Consumerism

The Environmental Advantages of Technology

Sustainable and Ethical Design in Terms of Colonialism, Extractivism, Mining, and Human Rights

Sustainable and Ethical Design in Terms of the Geopolitics of Materials

(Dis)ability, Access, and Human-Centered & Universal Design

Iterative Design

UX Design

Design at the Analog–Digital Interface

Design at the Hardware–Software Interface

Design at the Electronic–Mechanical Interface

Testing and Troubleshooting

Facility with Office-Productivity Tools

Facility with EDA Tools

Facility with Scientific and Computational Tools

Facility with Proprietary or Specialized Tools

IT Troubleshooting

Algorithmic Thinking

Working with Data Structures

Database Literacy

Using Open-Source Software

Developing Open-Source Software

---

[9] deep learning and foundation models (large language models, etc.), the blockchain, manufacturing, global commerce and the supply chain, rampant consumerism, etc.

Generative-AI Prompting Skills

Generative-AI Technical Knowledge

Generative AI's Ethical Issues and Pitfalls

Fairness, Explainability, Interpretability, Transparency, Justifiability, Contestability, Trustworthiness, Transferability, Informativeness, Stability, Robustness, Actionability, and Usability (User Focus) of Models [19] [20] [21] [22] [23]

Fairness, Accessibility, Assessibility, Trustworthiness, Robustness, and Anonymization of Datasets [19] [20] [21] [22] [23]

Cognitive Critical Thinking

Accuracy[10] in Scientific Critical Thinking

Precision in Scientific Critical Thinking

Skepticism[11] in Scientific Critical Thinking

Open-mindedness[12] in Scientific Critical Thinking

Awareness of Implicit Biases (Ethical & Social Critical Thinking)

Diversity Literacy (Ethical & Social Critical Thinking)

Equity Literacy (Ethical & Social Critical Thinking)

Injustice Awareness Ethical & Social Critical Thinking

Knowledge of UN Sustainability Goals and Grand Challenges (Ethical Leadership)

Agile and Other Team-based Development (Project Management)

Receiving Feedback as a Leader (Feedback in Ethical Leadership and Project Management)

Providing Feedback as a Leader (Feedback in Ethical Leadership and Project Management)

Injustice and Inequity in Access to Energy (Intersectional Awareness in Ethical Leadership)

Injustice and Inequity in Food Security & Public Health (Intersectional Awareness in Ethical Leadership)

Injustice and Inequity in Healthcare Access (Intersectional Awareness in Ethical Leadership)

Injustice and Inequity in Education Access (Intersectional Awareness in Ethical Leadership)

Injustice and Inequity in Hiring & Promotion (Intersectional Awareness in Ethical Leadership)

Injustice and Inequity in Entrepreneurship (Intersectional Awareness in Ethical Leadership)

---

[10] aiming to collect data and design experiments as free from bias as possible [26]

[11] being prepared to challenge ideas, even if they come from people or places of authority (Ibid.)

[12] willingness to give up one's strongly held views in the face of strong evidence to the contrary (Ibid.)

Mentoring

Peer Mentoring

Mutual and Cross-Mentoring

Journal Literacy

How to Use IEEE *Xplorer*

"What is a conference?"

"What is an abstract?"

"What is a research paper?"

Meeting Management

Supervising

Planning

Scheduling

Budgeting

Supply-Chain Management

Contracts

Technical Writing

Business Writing

Informal Written Communication

Oral Communication (including the "Elevator Pitch")

Designing and Making Presentations: Visualization

Designing and Making Presentations: Disability and Access

Devising and Running Technical Demonstrations

Debate and the Ability to Be Part of a Discussion

Entrepreneurship

Strategic Thinking

Leadership Humility

The Triple Bottom Line and Other Alternative Paradigms

Risk Management

Whistleblowing

Professional Web Presence

Online Portfolio: *Git*, *GitHub*, *GitLab*

Online Portfolio: *Hugging Face*, *Kaggle*

Online Portfolio: *Colab*, *Jupyter*/*JupyterLab*/*conda*/*Anaconda*

Online Portfolio: *LinkedIn*

Résumé, Thank-You-Letter, and Cover-Letter Writing

Interviewing Skills

On-the-Job Continual Learning

The *Fundamentals of Engineering* Exam

Master's Degree (Professional Continual Learning)

Ph.D. Degree (Professional Continual Learning)

Certificates (Professional Continual Learning)

Resilience, Tenacity, Failing Forward, and Building Confidence

Ability to Deal with Ambiguity and Complexity

Ownership and Accountability

Initiative (Being Proactive)

Curiosity and Motivation

Creativity and Innovation

Growth Mindset

Executive Function: Organization

Executive Function: Prioritization

Executive Function: Time Management

Executive Function: Emotional Regulation

Continual Self-Development

Grit[13]

Decision-Making

Problem-Solving

Networking

Etiquette

---

[13] There is a potential for clash with disabilities here.

Negotiation

Cultural Safety[14]

Cultural Humility

Empathy

Emotional Intelligence

Recognizing & Rewarding

Conflict Resolution

Active Listening in Teamwork

Division of Labor in Teamwork

Overlapping Roles and Supporting Team Members

Flexibility in Teamwork

Decision-Making in Teamwork

Community Building and Community Stewardship

Supporting and Sustaining Communities

Listening to Community Members in In-Person Interactions

Listening to Community Members in Dynamic Online Communication

Listening to Community Members in Hybrid Interactions

Presenting Information to Communities in In-Community Presentations

Presenting Information to Communities in Static Online Communication

Presenting Information to Communities in Hybrid Interactions

---

[14] Here are some descriptions of cultural safety taken from the article [24] and its references. “The focus is on the culture of the [engineer] and the [technological-development] environment rather than the culture of the ‘exotic other’ [stakeholders or community].” And the elements of cultural safety are as follows.

- acknowledging the barriers arising from inherent power imbalances;
- sharing decision-making with affected communities;
- turning focus back toward power, marginalization, and potential bias in the practitioner's perception and cognition;
- being prepared to interrogate or critique power, privilege, and racism, and to promote social justice;
- avoiding blaming the victim (such as in cultural-deficit theories);
- rejecting cultural essentialism ("Black people dance well." “All Asians are good at math.”);
- examining sources of repression, social domination, and structural variables such as class and power; practicing critical self-reflection, i.e., “stepping back to understand one’s own assumptions, biases, and values, and a shifting of one’s gaze from self to others and conditions of injustice in the world.” [25]

Communicating as Part of Communities: Written Advocacy

Communicating as Part of Communities: Oral Advocacy

Nurturing Community

References

[1] D. J. Staley and D. A. Trinkle, "The Changing Landscape of Higher Education," *EDUCAUSE Review,* vol. 46, no. 1, pp. 16-32, 2011.

[2] K. Palmer, "Americans See College's Value but Question It's Price," Inside Higher Ed, 9 August 2023. [Online]. Available: https://www.insidehighered.com/news/business/2023/08/09/americans-see-value-college-question-its-price. [Accessed 24 January 2024].

[3] J. Merisotis, "On The Value Of College, Higher Ed Has A 'Great Choir' Of Supporters—But Many People Can't Hear The Music," Forbes, 6 September 2023. [Online]. Available: https://www.forbes.com/sites/jamiemerisotis/2023/09/06/on-the-value-of-college-higher-ed-has-a-great-choir-of-supporters-but-many-people-cant-hear-the-music/?sh=26fd87a87a0e. [Accessed 24 January 2024].

[4] A. Kodey, J. Bedard, J. Nipper, N. Post, S. Lovett and A. Negreros, "The US Needs More Engineers. What's the Solution?," Boston Consulting Group, 13 December 2023. [Online]. Available: https://www.bcg.com/publications/2023/addressing-the-engineering-talent-shortage. [Accessed 24 January 2024].

[5] "Occupational Outlook Handbook, Electrical and Electronics Engineers," U.S. Department of Labor, Bureau of Labor Statistics, 6 September 2023. [Online]. Available: https://www.bls.gov/ooh/architecture-and-engineering/electrical-and-electronics-engineers.htm. [Accessed 24 January 2024].

[6] "Occupational Outlook Handbook, Computer Hardware Engineers," U.S. Department of Labor, Bureau of Labor Statistics, 6 September 2023. [Online]. Available: https://www.bls.gov/ooh/architecture-and-engineering/computer-hardware-engineers.htm. [Accessed 24 January 2024].

[7] "ASEE Corporate Member Council Survey for Skills Gaps in Recent Engineering Graduates," American Society for Engineering Education, 2023.

[8] "TUEE Transforming Undergraduate Education in Engineering Phase IV: Views of Faculty and Professional Societies," ASEE, Arlington, VA, 2017.

[9] P. Benner, "Educating nurses: a call for radical transformation-how far have we come?," *Journal of Nursing Education,* vol. 51, no. 4, pp. 183-184, 2012.

[10] C. B. Zoltowski, P. M. Buzzanell, A. O. Brightman, D. Torres and S. M. Edington, "Board # 159 : Understanding the Professional Formation of Engineers through the Lens of Design Thinking:

Unpacking the Wicked Problem of Diversity and Inclusion," in *ASEE Annual Conference & Exposition*, Columbus, Ohio, 2017.

[11] "Grand Challenges for Engineering: Imperatives, Prospects, and Priorities: Summary of a Forum," National Academy of Engineering, The National Academies Press, Washington, DC, 2016.

[12] K. L. Tonso, "Engineering identity," in *Cambridge Handbook of Engineering Education Research*, Cambridge University Press, 2014, pp. 267-282.

[13] E. Godfrey, "Understanding disciplinary cultures: The first step to cultural change," in *Cambridge Handbook of Engineering Education Research*, Cambridge University Press, 2014, pp. 437-456.

[14] D. Grasso and M. B. Burkins, "Beyond Technology: The Holistic Advantage," in *Holistic Engineering Education*, New York, NY, Springer, 2010, pp. 1-10.

[15] J. Rose, "After two Boeing 737 Max crashes, families are still seeking answers from DOJ," 25 April 2024. [Online]. Available: https://www.npr.org/2024/04/25/1247123011/boeing-crash-737-max-doj. [Accessed 25 April 2024].

[16] C. Isidore and G. Wallace, "Boeing whistleblower: 'They are putting out defective airplanes'," 17 April 2024. [Online]. Available: https://www.cnn.com/2024/04/17/business/boeing-whistleblower-safety-hearing/index.html. [Accessed 25 April 2024].

[17] E. H. Schwartz, "France Fines Google for $272 Million Over Generative AI Training Practices," 20 March 2024. [Online]. Available: https://voicebot.ai/2024/03/20/france-fines-google-for-272-million-over-generative-ai-training-practices/. [Accessed 25 April 2024].

[18] "Google's hidden AI diversity prompts lead to outcry over historically inaccurate images: Inserting depictions of diversity into AI images creates revisionist history, critics say," 22 February 2024. [Online]. Available: https://arstechnica.com/information-technology/2024/02/googles-hidden-ai-diversity-prompts-lead-to-outcry-over-historically-inaccurate-images/. [Accessed 25 April 2024].

[19] "Explainable AI: The Basics (Policy Briefing)," The Royal Society, London, 2019.

[20] R. Inam, A. Terra, A. Mujumdar, E. Fersman and A. V. Feljan, "Explainable AI – how humans can trust AI," 2021.

[21] "Explainable Artificial Intelligence (XAI) (Archived)," 2018. [Online]. Available: https://www.darpa.mil/program/explainable-artificial-intelligence. [Accessed 25 April 2024].

[22] "Science as an Open Enterprise," The Royal Society, London, 2012.

[23] N. Sambasivan, E. Arnesan, B. Hutchinson, T. Doshi and V. Prabhakaran, "Re-imagining Algorithmic Fairness in India and Beyond," in *Proceedings of the 2021 ACM Conference on Fairness, Accountability, and Transparency*, March 2021.

[24] E. Curtis, R. Jones, D. Tipene-Leach, C. Walker, B. Loring, S.-J. Paine and P. Reid, "Why cultural safety rather than cultural competency is required to achieve health equity: a literature review and recommended definition," *International Journal for Equity in Health,* vol. 18, no. 174, 2019.

[25] A. K. Kumagai and M. L. Lypson, "Beyond cultural competence: critical consciousness, social justice, and multicultural education," *Acad. Med.* , vol. 84, no. 6, pp. 782-787, 2009.

[26] R. A. Baron and M. J. Kalsher, Essentials of Psychology, Needham, MA: Allyn & Bacon, A Pearson Education Company, 2002.