The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #42357

Understanding the Skills and Knowledge Emphasized in Undergraduate Industrial Engineering Courses

Berenice A. Cabrera, University of Michigan

Berenice Alex Cabrera (she/her) is a Ph.D. student in Higher Education at the Marsal School of Education at the University of Michigan. She earned a B.A. in Biology and Latinx Studies and a minor in Chemistry from San Francisco State University (SFSU). She also earned a Master's in Cell and Molecular Biology from SFSU and a Master's in Higher Education from the University of Michigan. Alex taught biology at community colleges in California before attending the University of Michigan where her research interests pivoted to engineering education. Her current research interests focus on examining the messaging undergraduate engineering students receive with respect to the type of work that is valued in engineering. Her research is centered around the goal of making engineering curriculum more socioculturally relevant and the field more inclusive of women and students of color.

Shannon M. Clancy, University of Michigan

Shannon M. Clancy (she/they) is a Ph.D. candidate in Mechanical Engineering at the University of Michigan. She earned a B.S. in Mechanical Engineering from the University of Maryland, Baltimore County (UMBC) and an M.S. in Mechanical Engineering from the University of Michigan. Her current research focuses on idea development and ideation tools, divergent thinking, and engineering curricular practices and culture. Her research interests include front-end design practices, sociotechnical knowledge and skills in engineering, and queer student experiences in engineering. Their work is motivated by their passion for and experiences with inclusive teaching and holistic mentorship of students, seeking to reimagine what an engineer looks like, does, and who they are, especially for queer folks, women, and people of color, through empowerment, collaboration, and co-development for a more equitable world. Shannon is also a Senior Graduate Facilitator and Lab Manager with the Center for Socially Engaged Design.

Vibhavari Vempala, University of Michigan

Vibhavari (Vibha) Vempala is a PhD student in Engineering Education Research at the University of Michigan. Her research interests include access to opportunities, social networks, and career management of engineering students. Vibha received her B.S. in Engineering from the joint department of Biomedical Engineering at The North Carolina State University and The University of North Carolina at Chapel Hill and a M.S. in Biomedical Engineering from the University of Michigan.

Dr. Jingfeng Wu, University of Michigan

Jingfeng Wu is currently a PhD student at the University of Michigan majoring in Engineering Education Research. She holds a PhD in Chemical Engineering from University of Calgary in Canada, and a Bachelor of Science in Chemical Engineering at Chang'an University in China. Her research interests include engineering identity, design thinking, and engineering professional development.

Dr. Erika Mosyjowski, University of Michigan

Erika Mosyjowski is the Research and Faculty Engagement Manager in the Center for Socially Engaged Design within University of Michigan College of Engineering. She earned a PhD and MA in Higher Education from Michigan and a Bachelor's in Psychology and Sociology from Case Western Reserve University.

Dr. Lisa R. Lattuca, University of Michigan

Lisa Lattuca, Professor of Higher Education and member of the Core Faculty in the Engineering Education Research Program at the University of Michigan. She studies curriculum, teaching, and learning in college and university settings, particularly how fac

The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #42357

Dr. Joi-lynn Mondisa, University of Michigan

Joi Mondisa is an Associate Professor in the Department of Industrial and Operations Engineering and an Engineering Education Faculty Member at the University of Michigan Ann Arbor.

Dr. Shanna R. Daly, University of Michigan

Shanna Daly is an Associate Professor in Mechanical Engineering at the University of Michigan. She has a B.E. in Chemical Engineering from the University of Dayton and a Ph.D. in Engineering Education from Purdue University.

Understanding the Skills and Knowledge Emphasized in Undergraduate Industrial Engineering Courses

Abstract

In an effort to characterize how, if at all, required courses in industrial engineering (IE) facilitate students' development of sociotechnical engineering skills, this research examined the general content of required IE courses at a large, predominantly white institution in the Midwest. This paper drew on data generated for a larger research study that leverages Holland et al.'s figured worlds framework to explore the messaging that undergraduate engineering students at one institution received in their classes regarding valued knowledge and skills in their field. In this study, we analyzed observation data from recordings of seven required undergraduate courses in IE. We analyzed three randomly selected sessions from each course, with a total of 21 unique sessions observed. Our findings describe the practices that are and are not emphasized within and across required IE courses and the various manners in which these practices are discussed. Our findings show that in and across required IE courses, foundational technical knowledge is emphasized far more often than other knowledge and skills. Sociotechnical practices such as examining social and contextual considerations, exploring power, and engaging with stakeholders are seldom presented or discussed in IE classes, as is consistent with evidence from literature. Our characterization of emphasized engineering practices provides an important foundation for understanding what was communicated to students about the nature of engineering work in their field, messaging that has substantial implications for engineering students and those who persist in the field beyond their undergraduate studies.

Keywords: Industrial Engineering, Engineering Practices, Observations, Sociotechnical Skills

Introduction

A strong understanding of technical knowledge is necessary for all engineers, but understanding the context of engineering work and the ways in which it impacts individuals, communities, and the environment is also vitally important. There is increasing recognition among engineers, educators, and industry leaders of the importance of preparing engineers to account for these sociocultural dimensions [1]-[4]. We use the term "sociotechnical dimensions" or "practices" to refer to social or contextual factors such as ethics, engagement with stakeholders, and the recognition of power and identity and their role in engineering broadly. Environmental factors such as sustainability and the potential future impacts of engineering work are also categorized as sociotechnical dimensions as they draw attention to possible consequences to the natural environment. A call for broader engineering skills is reflected in the Accreditation Board for Engineering and Technology (ABET) student outcomes, a few of which directly denote the importance of students' ability to identify the ethical, cultural, and social impact engineers have on society [5]. However, engineering education continues to underemphasize or even omit non-technical aspects of engineering practice [3], [6], [7]. Insufficient attention to sociocultural content in engineering classes can limit students' ability to become holistically competent engineers [8] and potentially result in the development of future engineers whose designs further perpetuate social and systemic inequities, such as environmental pollution or inefficient designs that disproportionately affect vulnerable populations and risks human lives [9]. Additionally, emphasizing the sociotechnical dimensions of the field of engineering in undergraduate engineering courses can help attract and retain a more diverse population of students who value socially relevant engineering work [10]-[12].

A deep grounding in both technical and social skills and knowledge is particularly important in industrial engineering, a field focused on the improvement of systems and processes often integrating people, technology, energy, and information. Industrial engineering, compared to many other engineering fields, tends to focus more on human and business dimensions. While there has been some recognition of the importance of sociotechnical skills and knowledge within IE [13]-[15], more insight is required regarding the focus of undergraduate IE training and the kinds of messages IE coursework conveys to students about the nature of engineering work in the field. Understanding the extent to which these courses offer opportunities for students to cultivate the vital sociotechnical knowledge and skills that are becoming increasingly essential in the field of industrial engineering is crucial.

To understand the skills and knowledge emphasized in IE courses, and particularly how, if at all, these courses address sociotechnical content, our team analyzed classroom observation data from seven required IE classes at a large, R1, predominantly white institution in the Midwest. Our primary research objective was to discern and characterize the types of engineering knowledge and skills IE students most frequently encountered in their required courses. By identifying prevalent content in IE courses, we not only gain crucial insights into the skills and knowledge students are expected to acquire in their undergraduate studies, but also learn about the possible messages conveyed to students regarding the nature of engineering work. Our findings show that in and across required IE courses, foundational technical knowledge is emphasized far more often than other knowledge and skills. Sociotechnical practices such as examining social contexts, exploring power, and engaging with stakeholders are seldom presented or discussed in IE classes, as is consistent with evidence from literature.

Background

Engineering Practices and Culture

In alignment with the other branches of STEM, engineering has traditionally been perceived as an objective, apolitical, and neutral discipline. Engineering has long been viewed as a technical space that is independent of social or cultural considerations and should remain devoid of such matters [7]. However, integrating more sociocultural dimensions into engineering requires a substantive change in the undergraduate curriculum, which is currently heavily dominated by technical knowledge such as fundamental math and science theory, and related skills [1], [2], [16], [17].

Though technical knowledge is typically at the forefront of engineering course content, organizations such as the Accreditation Board for Engineering and Technology (ABET) underscore the importance of integrating both social and technical knowledge and skills in the engineering curriculum. For example, two key ABET criteria delineate the need for students to apply their technical knowledge to develop solutions to complex world problems which affect public health, welfare, and consider global, cultural, social, environmental, and economic factors. Another instance of such criteria 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.” [5]. In addition to the academic standards, industry leaders and educators alike emphasize the significance of equipping future engineers with skills to account for and meaningfully contribute to these sociocultural facets [1]-[4].

Industrial engineering distinguishes itself from other engineering disciplines through its emphasis on data analysis to improve social systems and processes. This field also focuses on human and business dimensions more so than other engineering disciplines [18]. Industrial engineering students are usually expected to become proficient in topics such as ergonomics and human factors, maximizing economic profit, systems engineering, operations research, manufacturing processes, and quality control [13], [19]. These examples of foundational knowledge are no doubt essential for industrial engineers to master, however, students often prioritize that knowledge over non-technical skills. In other words, "Students often have vague images of professional engineering work, and the images they do have are strongly colored by the experiences in their educational careers [including navigating…] textbook, problem set, and text-based mathematics and science courses. As a result, students often ignore, discount, or simply do not see images of engineering that emphasize its nontechnical, non-calculative sides…" [20].

Despite the inherent social dimensions within the subjects engineering students are expected to learn, sociotechnical skills are not integrated into the undergraduate engineering curriculum in substantial ways [21]. This gap highlights the need for a more comprehensive curriculum that connects the technical and social aspects of industrial engineering to ensure that students are competent in the sociotechnical nature of the multifaceted challenges of the industrial engineering field.

Figured Worlds Theoretical Framework

The figured worlds framework by Holland, Lachicotte, Skinner, and Cain [4], describes the way people participate within social and cultural domains that carry distinct meanings and are context dependent. Holland et al. describe a figured world as "a socially and culturally constructed realm of interpretation in which particular characteristics and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others." They also describe the ways in which figured worlds provide a lens through which individuals make meaning of their own and others' identities but are also shaped by the participation and actions of individuals within them. The relationship and interactions between an individual and their environment lead to the formation of identities and an understanding of what is normalized and valued within that environment.

Power plays a key role in the formation and maintenance of figured worlds. Inspired by Bourdieu, Holland et al. maintain that "a field is 'structure-in-practice,' and as such, is a world of relationships, of social positions defined only against one another." Individuals possess relative positions of power within figured worlds, and some may be excluded entirely from participation. One's position in a figured world is determined by the ways their actions are understood and valued by others and the extent to which these actions align with recognized and culturally meaningful forms of action, contributing to the preservation of the status quo.

In our larger study, we leverage the figured worlds framework to understand the culturally constructed beliefs about what it means to "do engineering" in two undergraduate fields, and the ways in which students' own values and ways of doing engineering align with these dominant beliefs. Through our larger data collection efforts, we explore how dominant beliefs about engineering work, conveyed through curricular messaging, shape and align, or misalign, with students' own understandings of what it means to do the work of engineering. Further, we seek to investigate the ways in which this alignment may have consequences for how students see themselves as engineers and the possibilities for students' continued participation in these engineering figured worlds.

In the present study, our focus centered on characterizing cultural beliefs about the nature of industrial engineering work through an examination of the skills and practices emphasized in required IE courses at one institution. Our theoretical framework offers a lens through which to examine students' learning experiences and how those experiences shaped students' understanding of the field of industrial engineering. Faculty hold relative power within course settings and decide the course content, how that content is communicated, and what is or is not valued in engineering through what they teach. As such, investigating the choices engineering faculty make with respect to the skills and knowledge emphasized provides insight into the dominant messaging students receive about engineering work and may offer insight into how engineering remains a predominantly technically focused discipline.

Methods

This paper utilizes one stream of data from a larger study that examines the messaging that undergraduate mechanical (ME) and industrial (IE) engineering students receive about the nature of engineering work through their course emphases, how these messages align with students' own interests and values, and the ways in which this alignment may shape students' career thinking and desire to remain in the field. The present study draws on classroom observation data from recordings of seven required undergraduate courses in IE.

Research Questions

Selecting industrial engineering as the focal point of this study provides valuable insights into how a discipline designed to prepare engineers for addressing societal issues imparts such knowledge and skills within the classroom. In this research study, we examined the engineering practices emphasized by instructors in required industrial engineering (IE) courses, guided by the following research questions:

- What engineering practices are most emphasized in required IE courses?
- How, if at all, do emphasized practices differ in various IE subfields?

Positionality of the Researchers

The research team consisted of doctoral students in the fields of higher education, mechanical engineering, and engineering education with backgrounds in biomedical engineering and chemical engineering. The team also included a staff researcher with a Ph.D. in higher education who studies engineering academic contexts and student experiences, a tenured professor in the school of education with a faculty appointment in integrative systems and design in the college of engineering, a tenured industrial engineering faculty member with a research focus in engineering education, and a tenured faculty member in mechanical engineering, also with a focus in engineering education.

All members of our team share a deep commitment to advancing engineering education and believe that the undergraduate engineering curriculum should align with the expected skills and knowledge of those in the field. As such, the entire research team- most of whom have had or currently hold an instructional role, believe that it is important to develop deep understandings of engineering course content and identify opportunities where engineering training may better incorporate social dimensions of the field, aligned with calls for better integration of these dimensions into engineering curricula. While we have varied social identities and personal and professional backgrounds, we share a desire to ensure the field of engineering can recruit and retain a diverse student body and believe attention to course content is one important and understudied potential influence in that effort.

Data Collection

After obtaining IRB approval, data were collected from recordings of seven required undergraduate IE courses. The decision to use course recordings rather than conduct in-person observations was influenced by the university's 2020 policy to automate course recordings as a response to COVID-19. Additionally, our team believed that using these recordings would be less intrusive than in-person observations and would also permit more detailed analysis with the ability to refer to data as necessary. To ensure that we could use data from course recordings of in-person classes, our team followed our institutional review board guidelines and had our research study approved by both the university general counsel and college leadership to safeguard proper handling of any incidental recording of student voice data that might be present in course recordings. Course recording videos were focused only on the course instructor and teaching materials, such as PowerPoint slides and a whiteboard background. Faculty were contacted via email by the faculty authors to participate in our study. In the recruitment message, we requested access to their course recording repository and a copy of the course syllabus. We assured participating faculty that our study was focused on understanding the range of skills and knowledge central to the work of the field of IE, with the ultimate goal of better supporting student learning, and that our study was not an evaluation of their teaching. We also provided an informed consent form which contained details and goals related to our study.

The seven required courses included in our study were recorded during Fall 2021 through Fall 2022 semesters. Class sessions ranged from 60-minutes to 120-minutes long, with an average class time of 98-minutes. For each course, we selected a subset of three individual course sessions using a random number generator, resulting in a total of 21 unique class sessions used in our analysis. We only selected three individual course sessions to balance in-depth data analysis. The first and last sessions from each class were excluded from our sample, as these often do not cover substantive or new content.

Classroom observation methods have been used by researchers to understand how teaching and learning occur in classrooms [22]-[27]. In the context of engineering education, classroom observations have become more common to conduct research related to curricular practices [28]. As our research questions centered on how engineering practices were taught and understanding how classroom time was utilized, classroom observations served as an ideal method through which to collect data.

To guide the data collection, the project leadership team (EM, LL, JLM, and SD) developed and iterated an observation protocol. The observation protocol consisted of 35 practices, which were drawn from literature on engineering competencies [1], [5], insights from student interviews probing the emphasized skills and knowledge in their required engineering courses, and interviews with engineering faculty and staff. The protocol was operationalized through a list of the engineering practices and their respective descriptions. The protocol was structured to capture the occurrence and manner in which observed practices were discussed in IE courses in 10-minute intervals. Our protocol was designed to capture both the presence and absence of a variety of relevant practices, as well as allow for a more descriptive account of the ways in which the practices were being integrated into the course by the instructor. The practices that were included in our observation protocol are listed in Table 1 below. The complete observation protocol can be found in the appendix.

Table 1: Engineering Practices Codebook

Engineering Practice Code	Practice Description
Business and Financial	Account for financial or economic considerations
Coding or Programming	Engage in computer coding or programming
Data Analysis	Engage in data analysis, processing, and interpretation
Data Collection	Collect data following proper procedures
Ethics	Weigh (often complex) ethical responsibilities
Experiment Design	Design or develop plans and procedures for experiments
Foundational Technical Knowledg	Learn or study fundamental engineering principles or technical knowledge
Future Impacts	Consider or account for potential future impacts of one's work
Human Factors and Ergonomics	Account for human factors and ergonomics -how bodies physically interact with a potential solution
Immediate context	Account for the immediate context in which a solution may be deployed
Information Gathering & Research	Gather information or conduct research needed to address a problem
Innovation (and Ideation)	Come up with innovative ideas and approaches
Interdisciplinarity	Engage in interdisciplinary collaboration or integrate ideas from other fields of study
Interpersonal Awareness	Demonstrate social awareness, empathy, and self-awareness in interactions
Iteration	Iterate on and improve on ideas or designs
Leadership	Use leadership skills to ensure teams work effectively
Lifecycle of a solution	Consider a design, product, or process over the course of its lifecycle
Logistics	Understand or coordinate logistics of a process, problem, or system
Modeling and Simulation	Develop or work with virtual models or simulations
Natural Environment	Account for the natural environment and/or issues of sustainability
Optimization	Engage in optimization to identify the best or most effective decision
Outcome predictions	Predict outcomes by drawing on engineering principles or methods
Power/ Position/ Identity	Consider dynamics related to the identities, positions, backgrounds, or relative power of self and/or others
Presentations on or Explanations o Work	Present on or verbally communicate about one's work or its value
Problem Definition	Define a problem to understand it and identify constraints and/or requirements
Project Management	Manage project work across multiple stages and/or multiple team members
Relationships and Tradeoffs	Account for relationships or tradeoffs between multiple aspects of a project and/or the larger system
Social Context	Account for the social or cultural context in which a problem is embedded
Solution Evaluation	Test and evaluate potential solutions

Stakeholders	Engage with or account for stakeholders' needs and perspectives
Tangible Artifacts Building	Build tangible artifacts as models, prototypes, or working products
Teamwork and Collaboration	Engage in teamwork or collaborate towards a common goal
Technical Communication	Prepare technical communication, including written reports and figures to represent work
Technical Details	Account for, develop, or refine the concrete details of (potential) solutions
Troubleshooting	Engage in troubleshooting to systematically identify or assess potential issues

Data Analysis

The data analysis team consisted of three doctoral engineering and engineering education students (SMC, VV, and JW), all of whom have a background in engineering. As such, these individuals were well-equipped to discern when a faculty was discussing a particular engineering practice in their course.

All three analysis team members familiarized themselves with the observation protocol by analyzing data from one engineering course not used in this study. This orientation process also served as an opportunity for the group to resolve any questions or issues that arose. To analyze data for the present study, the analysis team members independently coded data from three class sessions of an introductory engineering course and clarified any questions to reach agreement for reconciliation of each class observation. After the group reached consistency in their identification and description of course practices, they used a paired coding model in which two members independently coded a class session and then met to compare codes. Any questions or discrepancies were resolved during bi-weekly meetings during which EM offered guidance to address issues, particularly as it informed the other parts of the larger study.

Coding was accomplished by indicating if any of the practices in Table 1 were discussed in the observed classes. To ease the process of coding 60+ minute class sessions, the group utilized 10-minute intervals as a unit of analysis. The analysis team members used the observation protocol developed for this study to code the class recordings and identify the occurrence of practices within a 10-minute interval. Multiple practices could be coded within a 10-minute interval. For instance, each 60-minute class session was segmented into six 10-minute intervals and the team recorded whether a particular practice was discussed in each of these 10-minute intervals. The analysis team members also documented examples of instances when a particular practice was observed.

In an effort to maintain anonymity, the courses analyzed in this study have been clustered into "subfields", as shown in Table 2 below. Courses were grouped based on their related curricular content and the shared patterns of emphasized practices.

Table 2: Required Industrial Engineering Courses by Subfield

Subfields of Observed Courses
Introduction to the Field: One 100-level course
Optimization and Data Analytics: One 200-level and 300-level course
Probability and Statistics in Engineering: One 200-level and 300-level course
Design and Simulation: One 300-level and 400-level course

The first author calculated the average occurrence of a practice across courses per 10-minute interval, the length of class session, and number of class sessions. For example, each of the three Introduction to the Field class sessions were 80-minutes long, resulting in the analysis of eight 10-minute intervals across three class sessions observed. The “Foundational and Technical Knowledge” practice appeared in six of the 24 possible 10-minute intervals across the three course sessions, resulting in an average of 25% observed frequency. The same process was conducted across all seven IE courses for each of the three class sessions. In addition, the average practice frequency for each subfield was determined by calculating the average across the courses within that subfield.

The descriptive accounts of the ways in which engineering practices were discussed or integrated into the course by the instructor were also analyzed. The first author systematically reviewed each documentation of an observed practice and identified emergent themes across class sessions in a subfield. For example, in the Introduction to the Field subfield, BAC read through each observed practice and looked for common trends in the open-ended descriptions of how practices were emphasized in a given course.

Findings

In this section, we describe the most emphasized engineering practices observed in required IE courses as a whole and by subfields. Also included in this section are descriptions of how engineering practices appeared and were discussed in the observed class sessions. Findings are presented by subfield, beginning with an overview of emphasized practices across all required IE courses.

Emphasized Practices Across All Required IE Courses

Examining the most emphasized engineering practices across all levels of required IE courses, we found that “Foundational Technical Knowledge” (75%) was overwhelmingly the most frequently observed practice. “Optimization” was the next most frequently discussed or demonstrated practice in courses, observed in 28% of the 10-minute intervals across all class sessions, while “Modeling and Simulation” and “Human Factors and Ergonomics” practices were also observed relatively frequently (17% and 16%, respectively). With the exception of “Coding or Programming" (11%), all other practices accounted for 10% or less of our observations in required IE courses. The frequencies of all practices are shown in Figure 1 below.

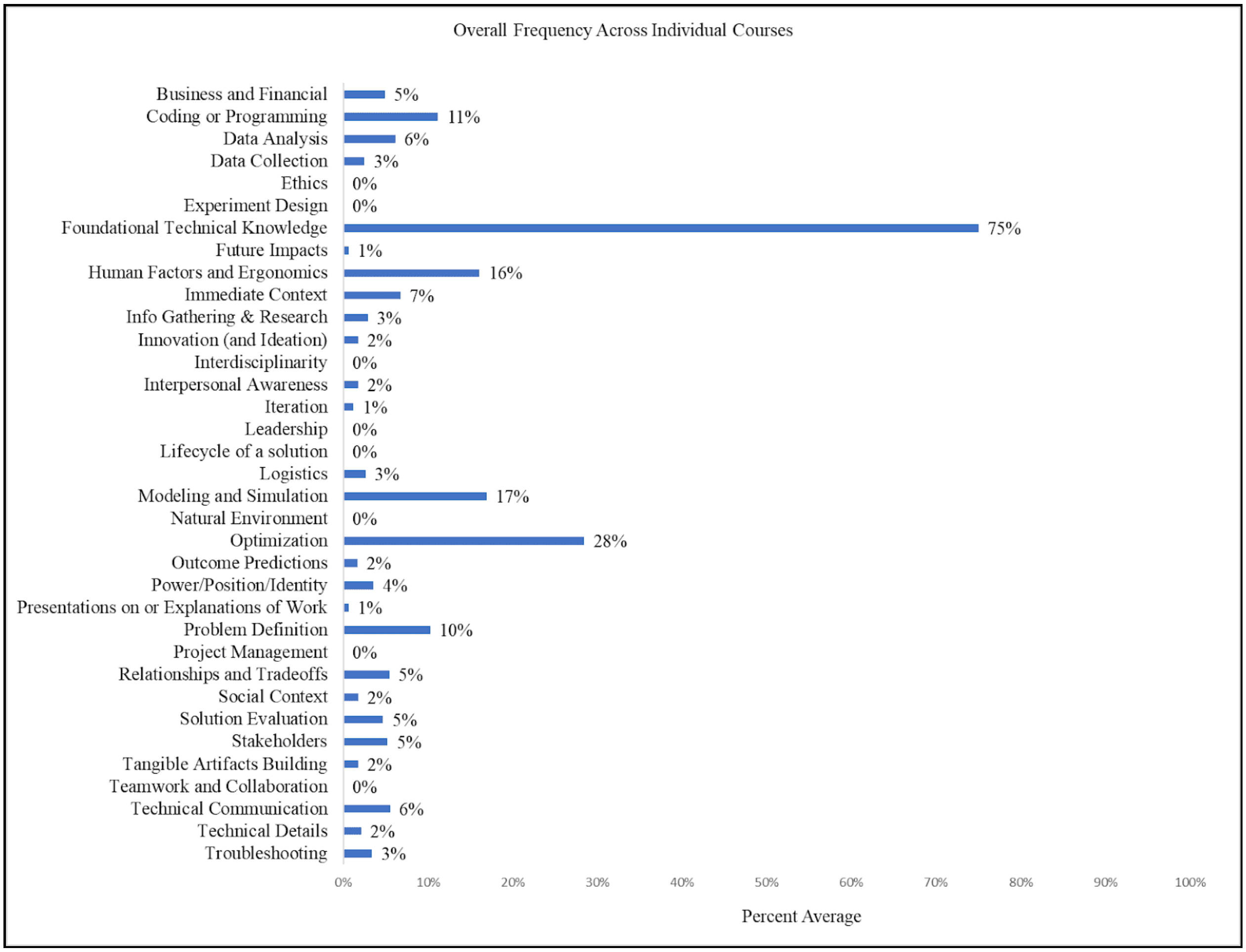

Figure 1: The percent average of engineering practice frequency across three class sessions of all required IE courses.

In the three class sessions of each course in this study, engineering instructors predominantly discussed topics related to “Foundational Technical Knowledge” by defining conceptual and theoretical knowledge or reviewing concepts through example problems. For instance, in one class session of an introductory course, an instructor spent the majority of class time defining the concept of biomechanics and demonstrating practice problems calculating force and torque. In every class session of the three higher level courses, instructors reviewed practice examples of concepts pertinent to their class covering topics such as integers, statistics, and branch and bound problems. In the remaining three upper-division courses, instructors introduced or continued their discussion of conceptual knowledge. Topics such as Markov chains, motion study, and random numbers were discussed.

Foundational and technical knowledge is demonstrated in the following examples. In one course, an instructor of an introductory IE course began the class by introducing biomechanics and illustrating its connection to other sciences: “So biomechanics is using the laws of physics and engineering concepts to describe motion undergone by the various body segments and the forces acting on the body segments." (Introduction to the Field subfield, IE Faculty)

In one mid-level course, an instructor demonstrated how to work through a branch and bound problem. The instructor completed their conceptual overview by directing students to refer to their problem-solving skills, specifically referencing students' knowledge on solving linear problems.

> "So, what we have here is a two-dimensional integer program, [it is] two dimensional because we have X one and X two, two decision variables, and an integer because of this constraint that we have here…in fact, we also have that they are positive integers. And so, what we did here is we said, "Ok, so it's a maximization problem, so we're going to try and solve it using the techniques that we know how to use, and the problems that we know how to solve are linear problems." (Optimization and Data Analytics subfield, IE faculty)

A final example of how "Foundational Technical Knowledge" appeared across all required IE courses was observed in a course taken by IE students nearing graduation. In this class, students learned about how random number generators operate, "First, let's examine a little bit of random number theory, or how random numbers for a particular distribution get generated." (Design and Simulation subfield, IE faculty) The remainder of this class session was spent overviewing the function and theoretical foundations of random number generators.

While the manner in which "Foundational Technical Knowledge" was discussed or demonstrated in courses from the excerpts above differed in subject matter, all examples showcased an emphasis on conceptual or theoretical knowledge. Furthermore, throughout the entirety of each of the class sessions highlighted above, it is important to note that at no point did students encounter material related to sociotechnical practices, including "Ethics," "Stakeholders," "Social Context," or "Power/Position/Identity." However, in other class sessions where these practices did arise, an instructor guided students in thinking about different levels of power in various settings. For instance, a professor recommended that students consider their own identity and prompted students to think about how their personal characteristics may influence engineering designs and consequently, the communities those designs may serve. In another class, a professor highlighted the importance of considering stakeholders and how they might interact with an engineered process.

These findings indicate that while it appears that there was a fair range of observed engineering practices across all required IE courses, they were not all discussed at substantial levels. Apart from "Foundational Technical Knowledge", other practices were discussed somewhat or rarely. This finding highlights that students often learned foundational engineering knowledge in the absence of its social and contextual implications.

Emphasized Practices by Subfield: Introduction to the Field

Within the course in the Introduction to the Field subfield, "Human Factors and Ergonomics" (38%) was the most prevalent practice discussed and/or demonstrated by the instructor. The next most observed practice was "Technical Communication" (33%) followed by "Foundational Technical Knowledge", "Power/Position/Identity", and "Stakeholders", with each accounting for 25% of our observations. There were also references to the role of "Interpersonal Awareness" (13%) and "Social Context" (13%), although these were no more frequent than other more technical topics, such as “Solution Evaluation” (21%), “Relationships and Tradeoffs” (13%), “Tangible Artifact Building” (13%), and “Troubleshooting” (13%). Frequencies of all practices are shown in Figure 2.

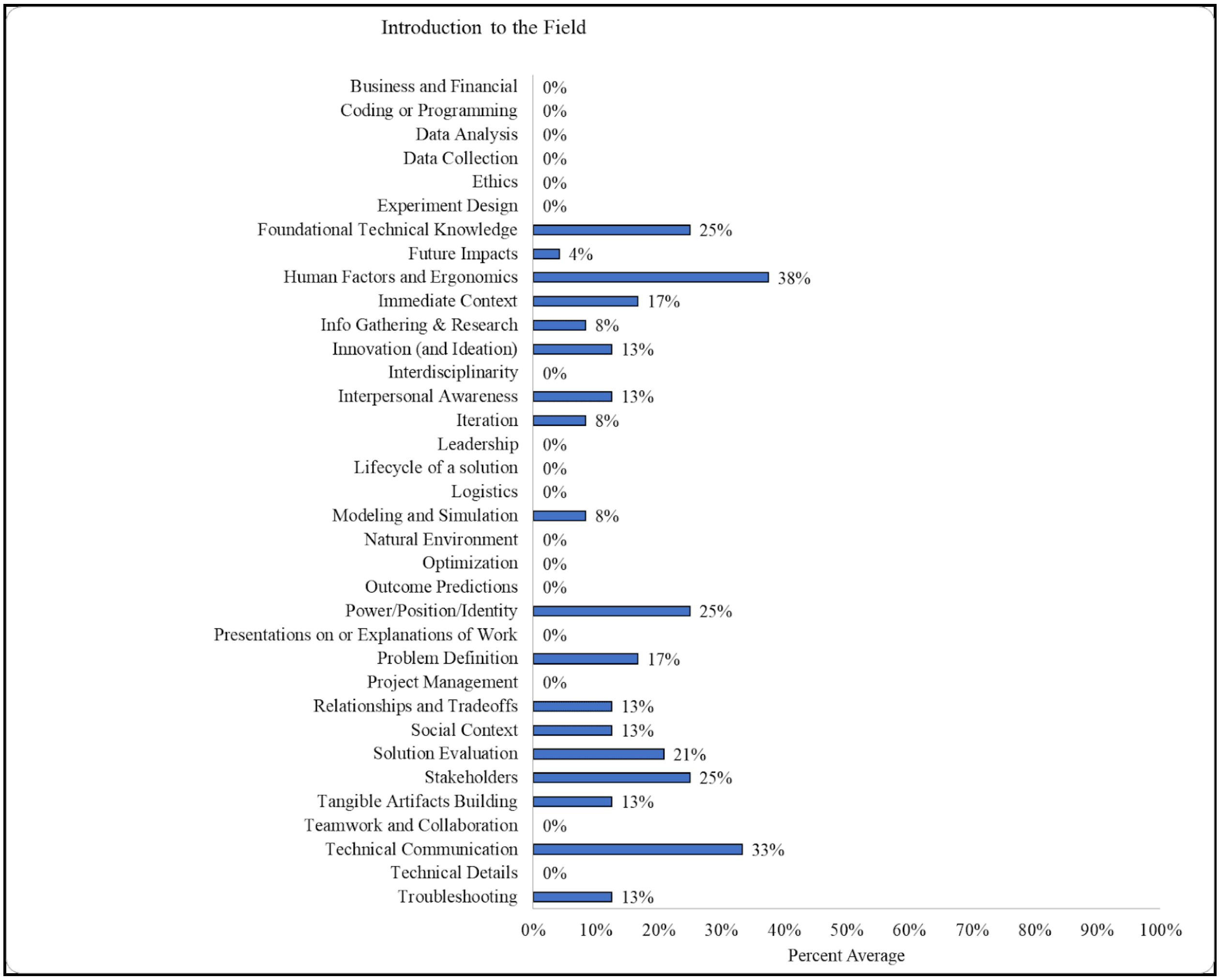

Figure 2. The percent average of engineering practice frequency across three class sessions of an introductory engineering course with an emphasis on industrial engineering.

In one example of course content related to “Human Factors and Ergonomics”, an instructor introduced anatomical concepts and later explained a particular assessment that students might use in their work as engineers:

> “Ok, so now I want to talk a little bit more about motions of the body and of the planes of the body. So, there are three planes of the body. The first one I’ll define is the sagittal plane. So that’s this plane here that is cutting the body in half. This is the transverse axis, right here. The transverse axis is perpendicular to the sagittal plane. Then, the next one I’ll define here is our coronal plane.” (Introduction to the Field subfield, IE Faculty)

In the same course, the instructor also discussed one risk assessment tool that students may encounter in the field, saying:

> "And we're going to look at one particular way of looking at risk. There's a lot of different ways to do it. But the RULA is the Rapid Upper Limb Assessment and it's a way to take some of these computational models that are pretty complex that I'll highlight to you and simplify them down for a quick kind of assessment that you can do in a workplace environment, for example." (Introduction to the Field subfield, IE Faculty)

The curricular content for this introductory course also included material in technical communication. The excerpts below were extracted from a class session where students learned about professionalism in written communication. Here, the instructor described key elements students were expected to include in their professional electronic communication, saying: "You want to make the topic and the purpose of your email is identified in the subject line and in the first few sentences of the [beginning of the email] ...then you want to provide a little bit of background information." The instructor then elaborated, emphasizing the importance of each of these elements: "We're looking for all of these elements. We're looking for: are you providing context? Are you explaining the purpose [of the email], are you providing all the information that was required?" (Introduction to the Field subfield, IE Faculty)

Among the remaining observed engineering practices in this subfield, "Foundational Technical Knowledge" was discussed at a similar rate as some sociotechnical dimensions of engineering work such as "Stakeholders" and the role of "Power/Position/Identity." Each of these engineering practices appeared in six of the 24 possible instances in the class sessions. In one class, an instructor touched on concepts related to both stakeholders and power by facilitating a class discussion on the various phases of a project. For example, an instructor explained that the "explore phase" often consists of many conversations with stakeholders and those who may interact with a design. Other discussions related to social elements included an instructor advising students to address their instructors as "doctor" or "professor" to avoid offending them, suggesting the need to attend to the academic hierarchies that exist in the university.

Emphasized Practices by Subfield: Optimization and Data Analysis

We observed a total of six class sessions from one 200-level course and one 300-level course in the Optimization and Data Analysis subfield. The average frequency across these six observed class sessions shows that "Foundational Technical Knowledge" (100%) was by far the most widely discussed practice in this subfield of required IE courses; it was emphasized in every observed class session. Unsurprisingly, given this category's name, the next most emphasized practice was "Optimization," which accounted for 75% of our observations in these courses. The emphasis on "Foundational Technical Knowledge" is further evidenced in the prevalence of discussions and demonstrations of "Coding and Programming" (22%), "Problem Definition" (22%), and "Modeling and Simulation" (16%). These courses also appeared to be highly focused in terms of curricular topics, with only nine of the 35 practices we examined discussed in the six class sessions observed in these two courses. Frequencies of all practices are shown in Figure 3.

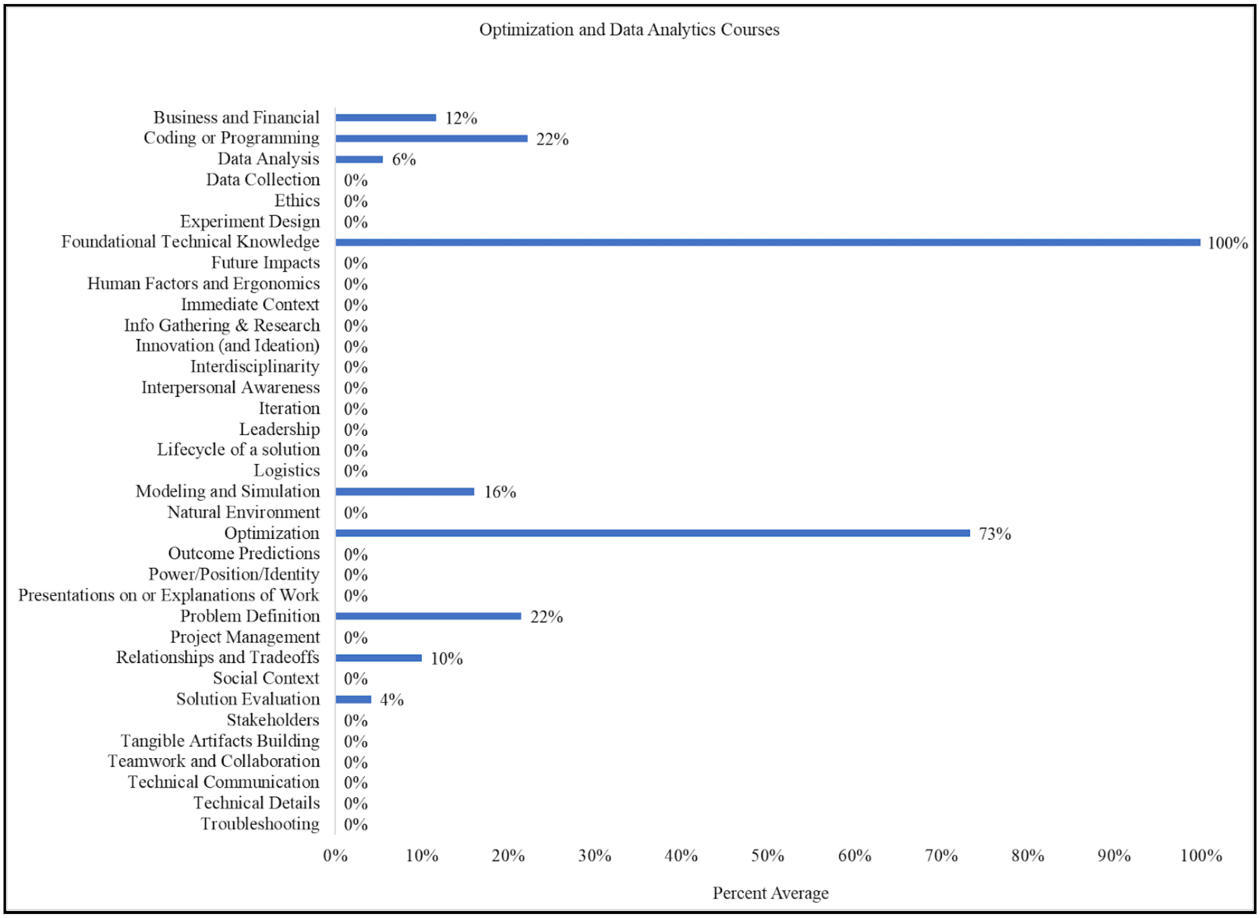

Figure 3. The percent average of engineering practice frequency across three class sessions of two courses with an emphasis on optimization and data analysis.

In this subfield, "Foundational Technical Knowledge" was presented by introducing and reviewing conceptual knowledge such as stochastic and deterministic models. In many cases, faculty demonstrated foundational and technical knowledge by demonstrating practice problems related to topics pertinent to the course. For example, in one class, an instructor reviewed concepts that will appear in the course midterm and prepared students by going over practice problems. One instructor referenced "Foundational Technical Knowledge" when teaching about inventory management with stable products and noted a similarity to another model:

> "So, basically, here we know that the demand is uncertain, but you know the distributional information of the demand. You know the random variable, so you know the distribution and you have a fixed order cost, K, and unit ordering cost, c per unit, holding cost, h, and penalty costs, b. This is the same as the deterministic EOQ model." (Optimization and Data Analysis subfield, IE Faculty)

In another example from this course, the instructor points out the relationship between expected cost and revenue and how to maximize the latter:

> "So, again, we want to minimize the total expected cost. Or, if you have a selling price, you then can turn this problem into a maximization of the revenue. So, the maximization

> of the revenue is the same as minimizing the cost." (Optimization and Data Analysis subfield, IE Faculty)

In the second course of this subfield, technical references to "Optimization" practices focused on the mathematics involved in evaluating possible solutions. Here, the instructor references linear programs (LP's), noting "There exists an optimal solution located at one of the extreme points of the LP's feasible region" and later explains how to solve two-dimensional LP's calling students' attention to the process: "What was the first thing that we did? Well, we drew the feasible region while the intersection of two constraints is an extreme point. And we'll see that precisely in this class." (Optimization and Data Analysis subfield, IE Faculty)

In all of the class sessions observed in this subfield, there was a notable absence of sociotechnical practices. Sociotechnical practices such as "Ethics," "Power/Position/Identity," "Stakeholders," and "Social Context" did not appear in the six class sessions in our data for this subfield. This finding suggests that while students are gaining foundational knowledge related to optimization and developing their data analysis skills, they may be doing so without opportunities to learn or practice applying their foundational knowledge to social issues or considerations.

Emphasized Practices by Subfield: Probability and Statistics in Engineering

This subfield included one 200-level and one 300-level course. Throughout the six class sessions of these courses, "Foundational Technical Knowledge" (100%) was again the central focus of the course material in each session, as seen in Figure 4. The prevalence of this practice was even more apparent than in the Optimization and Data Analysis subfield as there were fewer other practices observed at all in these courses. All of the topics covered in these class sessions focused on teaching statistical concepts and mathematical techniques.

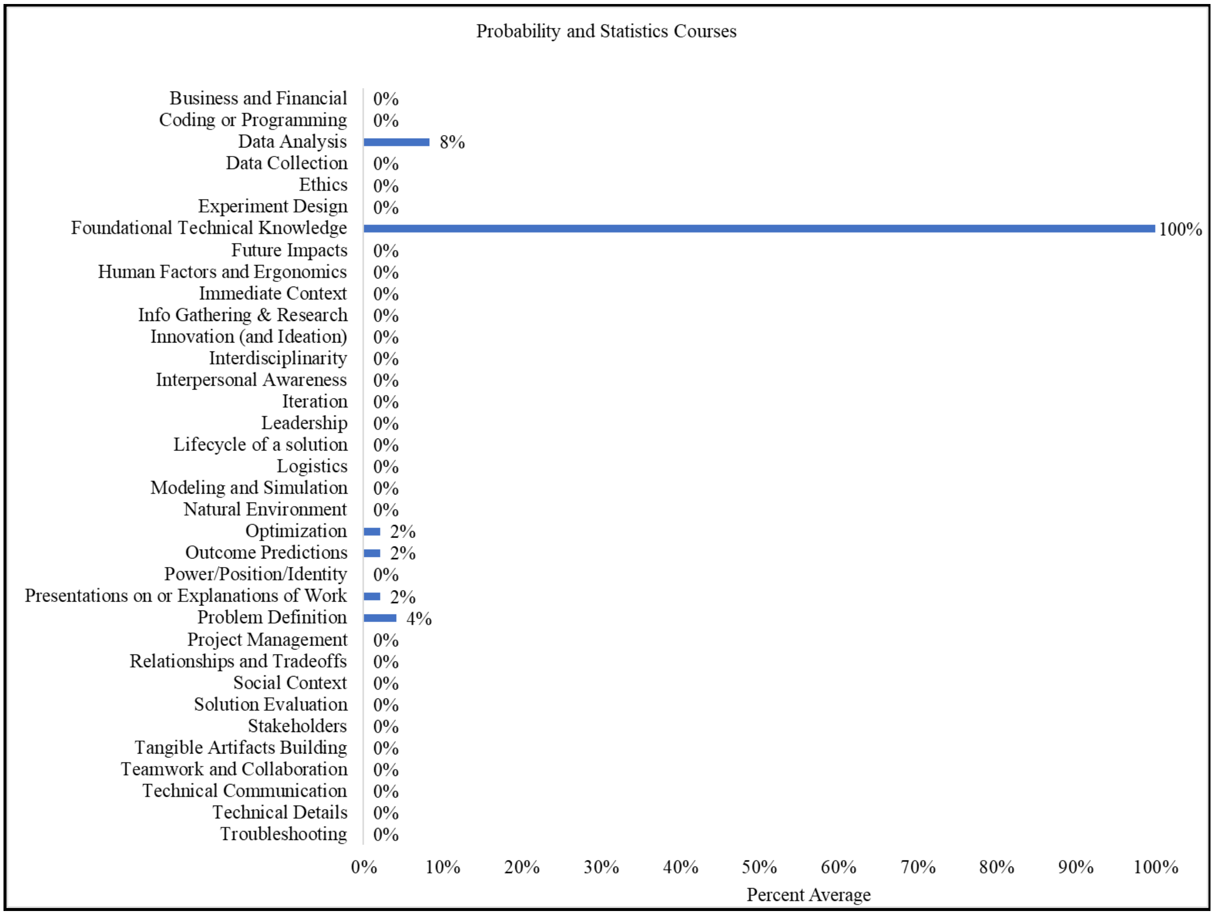

Figure 4. The percent average of engineering practice frequency across three class sessions of two courses with an emphasis on probability and statistics for engineers.

In the example that follows, an instructor began the class by reminding students of previous class discussions. The instructor then introduced random variables and shared the intention to start with the most important types of random variables, which he identified as continuous variables. It is noteworthy that aside from analyzing an example problem and commenting that exams were not cumulative, the instruction in this class session focused entirely on technical knowledge as illustrated below:

> “We have started our discussion on just the general notion of discrete random variables. And then, after discussing the general notion of the security random variables, we spoke about specific discrete random variables including the Bernoulli, the binomial, and the hypergeometric distributions. Today, I will talk a little bit about the general motion of continuous random variables, and then I will discuss specific random variables and I will start by discussing the most important continuous variables, which is the normal distribution.” (Probability and Statistics in Engineering subfield, IE Faculty)

In another course taught by a different professor, the use of Markov chains in managing engineering systems is the focus of the class session, and the instructor seeks to connect the lesson to the concerns of practicing engineers:

> “So, the idea there is you have systems that you need to look at, that you have to be able to manage continuously, have to be able to see what’s happening at any point in time. So, it’s not like you go out and you come back on, and you say ‘Hey, what’s happening here?’ It’s a system that you really care about, knowing what’s happening at every single point in time. And for those systems, we can do continuous time. Markov chains continuously look at those systems, the way we model those systems is going to be something similar to what we had in the discrete time.” (Probability and Statistics in Engineering subfield, IE Faculty)

As reflected in Figure 4, there was no discussion of sociotechnical concepts in the six class sessions observed in this subfield. Of all the subfields included in this study, this one appears to be the most technically focused.

Emphasized Practices by Subfield: Design and Simulation

The Design and Simulation subfield included one 300-level and one 400-level course. In the classes within this subfield, we observed more variety in the practices discussed than in any other subfield, still, “Foundational Technical Knowledge” (50% of observations) was the most common practice. The subsequent observed practices were also technically-oriented: “Modeling and Simulation” (39%), “Human Factors and Ergonomics” (38%), “Optimization” (24%), “Coding or Programming” (17%) and the “Immediate Context” (15%). Class observations also included discussions of “Stakeholders” and “Business and Finance”, but only accounted for 6% of observations each. There were slightly more references to “Logistics” (9%), “Data Collection” (8%), and “Data Analysis” (8%) in these courses as shown in Figure 5.

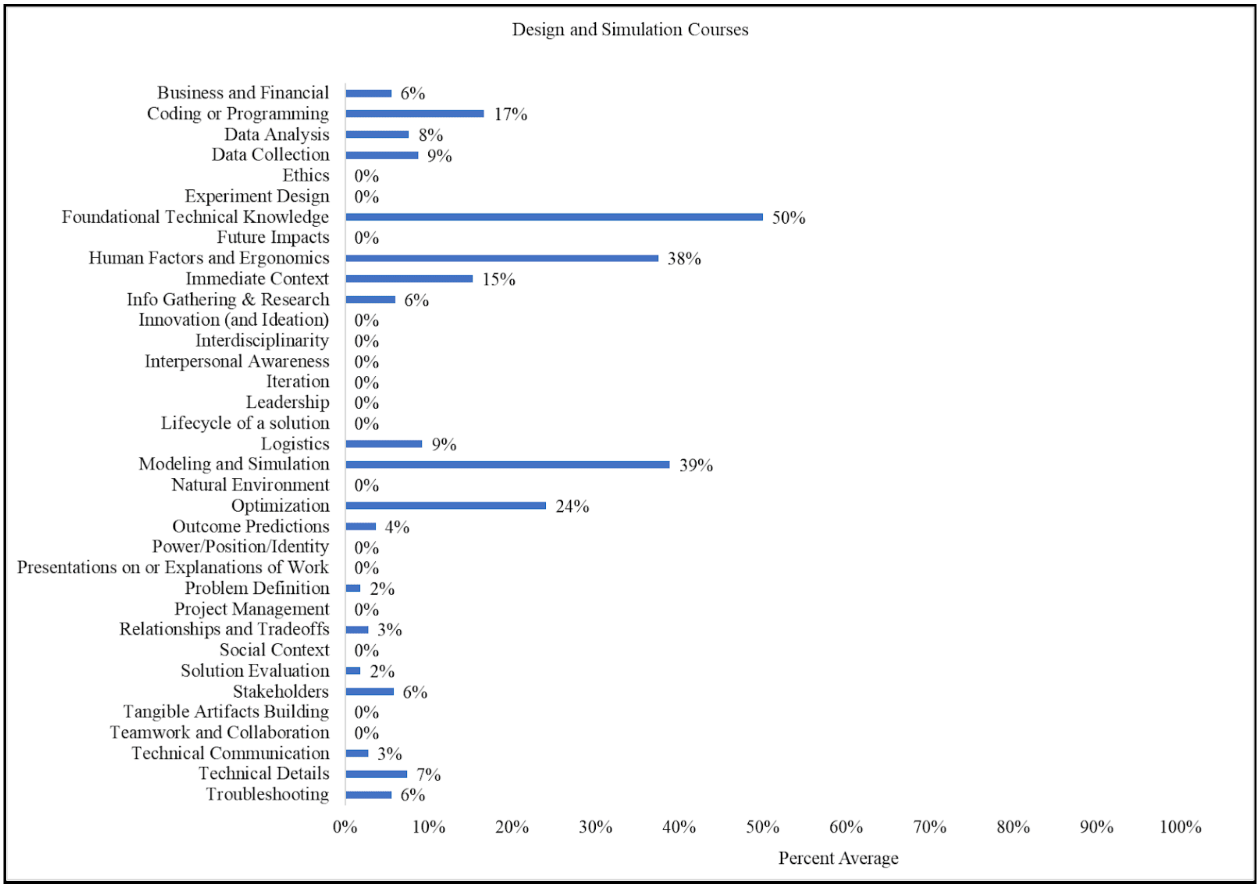

Figure 5. The percent average of engineering practice frequency across three class sessions of two courses with an emphasis on design and simulation.

Faculty from courses in this subfield exemplified “Foundational Technical Knowledge” by overviewing concepts about motion study and motion-time management (MTM) during discussions on enhancing efficiency for specific processes. Faculty underscored the purpose of understanding MTM as a measure to gauge task completion times. Another guest instructor of a course in this subfield demonstrated foundational knowledge by sharing the theory behind random number generators and conducted a ProModel simulation to support learning around goodness of fit tests.

In the following example, the instructor aimed to exemplify the distinctions between the work of researchers and practicing engineers in motion studies. The distinction lies in illustrating the engineer as a technician who applies established methods created by others, i.e. researchers. However, by the instructors’ conclusion, the instructor tries to avoid denoting an overly rigid demarcation between these two roles by amplifying the interconnectedness of research and technical work in engineering:

> “Basically, you can see that motion study is, roughly speaking, divided into two different components. One is the researchers’ work and one is the engineers’ work. What’s the difference between the two? Researchers are the people who establish the fundamental method for other people to use. Engineers are the people who apply the methods already

> developed by the researchers in a concrete workplace. Not necessarily totally separated but there is a different emphasis there." (Design and Simulation Subfield, IE Faculty)

We also observed an instructor of a different course emphasize modeling and simulation techniques, particularly the use of random number generators in simulation models, saying:

> "One of the things about knowing a little bit about random number generation is the fact that we can actually increase variability or decrease variability of some of these random streams that we use in a simulation model. So, we're going to see how that works, in particular, with respect to Promodel." (Design and Simulation Subfield, IE guest instructor)

Faculty also discussed how such techniques may be applied in the workplace, as is noted in the excerpt below where the instructor focused on the question of how to decide among alternatives for the layout of an actual facility, and explained the challenges associated with random numbers:

> "One common thing to do sometimes is that if you are going to, say, make changes to the current layout of a facility, and you find out that, actually, between the two alternatives, the differences are not too big, one potential thing that you can do is actually minimize variability because when you compare systems that are close to each other, in terms of the changes, sometimes, the variability you introduce with random numbers might be masking the actual differences in the layout." (Design and Simulation Subfield, IE Faculty)

In the six class sessions observed in this subfield, there were two instances of discussion of sociotechnical practices. An instructor briefly mentioned that an initial step to commencing a time study procedure should include a conversation with stakeholders so that there is an understanding of the purpose of the study. In a separate class, the instructor discussed the importance of prioritizing the needs of stakeholders in engineering projects. There was no emphasis or discussion of other sociotechnical engineering practices in the remainder of the class observations in this subfield.

Discussion

This study elucidates the engineering skills and knowledge that are and are not emphasized within and across required IE courses, and the various ways in which these practices were discussed. Our characterization of emphasized engineering practices provides an important foundation for understanding what is communicated to students about the nature of engineering work in industrial engineering, messaging which has substantial implications for the population of students who enter and persist in the field beyond their undergraduate studies. Overall, our findings indicate that foundational and technical knowledge dominate required course content in IE, suggesting that students may not encounter course material that appropriately orients them to the sociotechnical nature of engineering work. As such, the lack of sociotechnical course content can result in students being ill-prepared to incorporate contextual factors into their technical work, which is necessary to address the complex problems with societal implications they will likely encounter as engineers. Additionally, the omission, or only occasional mention, of sociotechnical engineering practices may signal to students that the field of engineering is narrowly technical with little need to consider social matters.

Undergraduate IE students in this study encountered the most variation in attention to engineering practices at the beginning and end of their academic program. The Introduction to the Field subfield showcased 18 of the 35 engineering practices included in our study, though the majority of the most discussed practices in this subfield were practices that required technical knowledge. In addition to technically leaning practices, the Introduction to the Field course also presented material, albeit sporadic, related to the social implications of engineering work. While topics related to power, social implications of engineering work, and engagement with stakeholders were discussed fairly frequently in this introductory course, these discussions were not necessarily structured to promote student reflection on what they would mean for their future work as engineers. These findings suggest that even in introductory courses, which often cover a wider breadth of content and serve as students' initial formal exposure to the field [30], students were briefly exposed to material that revealed the sociotechnical dimensions of engineering work, but not engaged in robust examinations of these topics.

As such, it is possible that students learn early on that matters of social context are separate from the work of engineers. Examining this finding through the lens of the figured worlds framework [4], we can infer that students' perception of engineering and engineering work is influenced in part by their participation in the context of their introductory courses. Additionally, if students' understandings of engineering work and culture are shaped through participation in course contexts, students may learn that social issues are completely separate from and not valued in engineering-related work.

Similarly, in the Design and Simulation subfield that included courses students are likely to enroll in as they near graduation, 19 of the 35 engineering practices were observed. Here, "Foundational Technical Knowledge" was the most emphasized practice, but "Human Factors and Ergonomics" and "Modeling and Simulation" were also emphasized substantially. At this stage of their program, students who aim to conduct socially relevant engineering work would benefit from frequent class discussions about the social impact of their future work. As students approach graduation and enter the workforce, many will rely on their knowledge acquired from their undergraduate studies. This underscores the importance of a sociotechnical engineering curriculum that supports the interplay between society and engineering. While there was some diversity in the material discussed in these courses, two of the sociotechnical topics that appeared in the introductory course – "Power/Position/Identity" and "Social Context" – were not discussed in the six class sessions observed in this subfield. References to "Stakeholders" were only 6% of observations in these courses. It is possible that these topics were discussed in other class sessions not included in our study. However, our random selection of class sessions offered insight into course material that IE students typically encounter at various points of an academic term. Given this sampling, it is unlikely that sociotechnical concepts were discussed substantially in other class sessions not included in our study.

Although students encountered a fairly wide range of topics in courses in the beginning and end of an industrial engineering program, the prioritization of foundational knowledge was heavily emphasized while social or contextual skills and knowledge were not. Interestingly, this finding is consistent with other studies of engineering course emphases. For instance, [3] examined the curricular emphases in six fields of engineering including industrial engineering, as well as biomedical/bioengineering, chemical, civil, electrical, and mechanical engineering. This study, conducted in 2007-08, utilized a sample of 31 U.S. engineering schools, chosen for their representative institutional missions and level of highest degrees offered. It revealed that introductory and design courses – typically offered at the beginning and end of students' undergraduate programs – are key stages where students are first introduced to professional skills and sociotechnical knowledge. Tenure-track and non-tenure track instructors' reports on their own courses in these fields, showed that design courses carry much of the responsibility for teaching the kinds of sociotechnical knowledge that ABET and many other reports on engineering education, such as [29], identified as critical to effective engineering. Moreover, the study showed that in addition to promoting sociotechnical knowledge and skills, these courses also give students practice in applying foundational and technical knowledge. While the referenced study did not disaggregate findings on industrial engineering, the patterns we observed in our study are consistent with those reported in the referenced study, and both of these sets of findings are consistent with emerging findings from our observations of required courses in mechanical engineering in the same institution, which will be presented in another paper.

In contrast to courses in the Introduction to Engineering and Design and Simulation subfields, observed course sessions in the Probability and Statistics in Engineering and Optimization and Data Analytics subfields displayed low levels of engineering practice variability. The courses within the Optimization and Data Analytics subfield focused *purely* on technical knowledge. Further, the emphasis was primarily on foundational or abstract technical content, with less frequent mention of more applied technical practices such as data analysis or accounting for concrete technical details of a solution. These findings are consistent with prior research on the ways undergraduate engineering education often presents a narrow representation of engineering practice through a disproportionate emphasis on abstract knowledge over more applied forms of engineering work [20].

In this foundational work, our observations of required IE courses across lower- and upper-division levels reveal the variations in emphasis on 35 engineering practices in these courses. When these observations are combined, we gain insight into the overall image that instructors present to undergraduate students about the field and occupation of industrial engineering. That image is instilled through strong and continual emphasis on technical knowledge and skills – which is essential to engineering practice – but there is remarkably little attention to other kinds of professional knowledge and skills. Moreover these "other" sociotechnical dimensions of engineering work are not frequently encountered after students take their first engineering course. To those who view industrial engineering as the most human-centered engineering field, it may be surprising to learn from our findings that there is infrequent discussion of or opportunities for students to engage with stakeholders, consider the social contexts of engineering, and explore one's positionality and its impact on their work.

There are continued calls to the field of industrial engineering to recognize the importance of sociotechnical skills and knowledge within IE, especially since findings similar to our observations have appeared in other related studies [13], [14], [15]. However, one ongoing challenge with changing the way IE is presented has been the lack of evidence around which curricular emphases to shift.

While additional research on the undergraduate IE curriculum is clearly warranted, the findings from this study provide the foundation on which to build a greater understanding of how engineering curricula shape student learning about engineering as a field of professional practice. This study presents one strand of data that we are collecting through a multi-method, multi-year study. In future papers, we will combine this descriptive data on the curricular emphases in required courses in industrial engineering in this setting with survey data from a census of the IE majors who have taken these courses and interviews with a subset of those students. Consistent with the figured worlds conceptual framework that guides the larger study, and our goal of understanding the messages that undergraduates received about the "nature" of engineering work, our findings will be combined into a case study of industrial engineering education in research intensive institutions that will aid understanding of how engineering curricula shape not only students' understanding of their field, but their thinking about their place in that field given their personal values and interests. Our ultimate goal is to gain a greater understanding of how the content of engineering curricula contributes to students' understanding both of what it means to "do engineering" and the ways in which students' own values and ways of doing engineering align with these dominant beliefs. These personal assessments of fit, we contend, can shape students' desire to remain in the field after graduation.

Limitations

This study has limitations that may have shaped our findings. First, this study was constrained by the examination of three class sessions per course. With a limited sample of classroom observations, a comprehensive overview of emphasized skills and practices is difficult to ascertain. It is possible that additional engineering practices were named in the course sessions not observed by our team. Relatedly, only one 400-level course was included in the study. The findings from this subfield could be strengthened by the inclusion of additional 400-level courses. Additionally, this study only examined courses from a single IE program at a research intensive institution. To expand on this work, future research should include multiple institutions and include various institution types. Another limitation of this study was the exploration of only required IE courses. We focused our analysis on required IE courses, as these courses represent the content that all undergraduate IE students encounter. However, a more comprehensive analysis of the messaging that engineering students receive in their IE courses would observe all of the IE courses that students need to complete for their undergraduate engineering program.

Implications

As outlined by ABET, in addition to a strong foundation in technical knowledge, students should be able to apply such knowledge in their future work and take into account social contexts. To prepare students with such skills, engineering courses and programs should develop and cultivate a deep commitment to ensuring students become sociotechnically competent engineers. One step toward that goal is to integrate social and contextual framing within the engineering curriculum. As indicated in many examples in this study, engineering course content is often introduced to students from a technical standpoint. Incorporating social, environmental, economic, and ethical considerations could engage students who enter engineering with a proclivity for social interests and also provide a more comprehensive representation of the work of engineering. Faculty could integrate sociotechnical elements into the predominantly technical engineering curriculum that exists today. By doing so, students may be provided with opportunities to reflect on their positionality, consider their power and privilege relative to others, and examine how that might play into their future engineering work. These approaches could enrich the overall learning experience and prepare students to address the complex challenges they will face in their engineering careers. More importantly, students might be better prepared to think critically about existing and future designs, focusing on dismantling social and systemic inequities.

Conclusion

The primary objective of this study was to discern the most emphasized engineering practices in required industrial engineering courses. Guided by Holland et al.'s figured worlds framework, our goal was to characterize how required IE courses might facilitate students' development of sociotechnical engineering skills. Gaining a more profound understanding of the curricular decisions made by engineering faculty regarding the allocation of class time allows us to discern the emphasized skills and knowledge in IE courses. Through classroom observations, we concluded that foundational technical knowledge persists as the most discussed course content across all levels of IE required courses. We also found that sociotechnical practices such as considering the social or cultural context in which engineering work is embedded, or engaging with stakeholders, are only somewhat discussed at the onset and end of students' industrial engineering program. Courses that students encounter in the middle of their program appear to be purely technical. There is growing recognition of the sociotechnical dimensions of engineering, especially within industrial engineering. If the field values these sociotechnical aspects, then it could be highly beneficial to align undergraduate engineering education with such sociotechnical elements to better equip students with the necessary skills and knowledge to become socially engaged and innovative engineers.

References

1. H. J. Passow and C. H. Passow, "What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review," *J. Eng. Educ.*, vol. 106, no. 3, pp. 475–526, 2017.
2. B. Palmer, P. T. Terenzini, A. F. McKenna, B. J. Harper, and D. Merson, "Design in Context: Where Do the Engineers of 2020 Learn this Skill?" in *Proc. 2011 ASEE Annual Conf. & Exposition*, 2011, pp. 22–430. [Online]. Available: https://peer.asee.org/17711
3. L. R. Lattuca, P. T. Terenzini, D. Knight, and H. K. Ro, "2020 Vision: Progress in Preparing the Engineer of the Future," 2014. [Online]. Available: https://deepblue.lib.umich.edu/handle/2027.42/107462
4. D. C. Holland, W. S. Lachicotte, D. Skinner, and C. Cain, "Chapter 3: Figured Worlds," in *Identity and Agency in Cultural Worlds*, Cambridge, Mass.: Harvard Univ. Press, 1998.
5. Engineering Accreditation Commission, "Criteria for Accrediting Engineering Programs, 2022 – 2023," 2021. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/
6. D. Riley, "Engineering and Social Justice," *Synth. Lect. on Eng., Tech., and Soc.*, vol. 3, no. 1, pp. 1–152, 2008.
7. E. A. Cech, "The (mis) framing of social justice: Why ideologies of depoliticization and meritocracy hinder engineers' ability to think about social injustices," in *Eng. Educ. for Social Justice*, Springer, 2013, pp. 67-84.
8. W. Faulkner, "'Nuts and Bolts and People': Gender-Troubled Engineering Identities," *Soc. Studies of Sci.*, vol. 37, no. 3, pp. 331–356, 2007. doi:10.1177/0306312706072175
9. D. Nieusma and D. Riley, "Designs on development: Engineering, globalization, and social justice," *Eng. Studies*, vol. 2, no. 1, pp. 29–59, 2010. doi:10.1080/19378621003604748
10. K. Litchfield and A. Javernick-Will, "I Am an Engineer AND: A Mixed Methods Study of Socially Engaged Engineers," *J. Eng. Educ.*, vol. 104, no. 4, pp. 393–416, 2015.
11. C. Swan, K. Paterson, and A. R. Bielefeldt, "Community engagement in engineering education as a way to increase inclusiveness," in *Cambridge Handbook of Eng. Educ. Res.*, Cambridge: Cambridge Univ. Press, 2014, pp. 357–372.
12. J. L. Smith et al., "Giving Back or Giving Up: Native American Student Experiences in Science and Engineering," *Cultural Diversity & Ethnic Minority Psychol.*, vol. 20, no. 3, pp. 413–429, 2014. doi:10.1037/a0036945
13. D. Nazzal and J. Zabinski, "Introduction of Sustainability Concepts into Industrial Engineering Education: a Modular Approach," 2015.
14. H. Eskandari, S. Sala-Diakanda, S. Furterer, L. Rabelo, L. Crumpton-Young, and K. Williams, "Enhancing the undergraduate industrial engineering curriculum: Defining desired characteristics and emerging topics," *Education + Training*, vol. 49, no. 1, pp. 45–55, Feb. 2007, doi: 10.1108/00400910710729875.
15. S. Daniel, D. Popejoy-Sheriff, K. J. Min, and L. Potter, "Abet Outcome Assessment And Improvement Through The Capstone Design Course In An Industrial Engineering Curriculum," in *2006 Annual Conference & Exposition Proceedings*, Chicago, Illinois: ASEE Conferences, Jun. 2006, p. 11.149.1-11.149.12. doi: 10.18260/1-2--1082.

16. National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: National Academy of Engineering, 2004. [Online]. Available: http://www.nap.edu/catalog.php?record_id=10999
17. A. Mazzurco and S. Daniel, "Socio-technical thinking of students and practitioners in the context of humanitarian engineering," *J. Eng. Educ.*, vol. 109, pp. 243–261, 2020. [Online]. Available: https://doi.org/10.1002/jee.20307
18. Grainger Engineering Office of Marketing and Communications, "Industrial Engineering degree," Industrial & Enterprise Systems Engineering | UIUC. [Online]. Available: https://ise.illinois.edu/undergraduate/industrial-engineering-degree
19. J. Matson, J. Mozrall, D. Schaub, and P. Patterson, "An Industrial Engineering Body Of Knowledge?," in *2007 Annual Conference & Exposition Proceedings*, Honolulu, Hawaii: ASEE Conferences, Jun. 2007, p. 12.211.1-12.211.11. doi: 10.18260/1-2--2517.
20. R. Stevens, A. Johri, and K. O'Connor, "Professional Engineering Work," in Cambridge handbook of engineering education research, New York: Cambridge University Press, 2014, pp. 119–137.
21. E. A. Cech, "Culture of Disengagement in Engineering Education?" *Sci., Tech., & Human Values*, vol. 39, no. 1, pp. 42–72, 2014. [Online]. Available: https://doi.org/10.1177/0162243913504305
22. T. J. Weston, C. N. Hayward, and S. L. Laursen, "When Seeing Is Believing: Generalizability and Decision Studies for Observational Data in Evaluation and Research on Teaching," *American Journal of Evaluation*, vol. 42, no. 3, pp. 377–398, Sep. 2021, doi: 10.1177/1098214020931941.
23. S. L. Laursen, M.-L. Hassi, M. Kogan, and T. J. Weston, "Benefits for women and men of inquiry-based learning in college mathematics: A multi-institution study," *J. for Research in Mathematics Education*, vol. 45, no. 4, pp. 406–418, 2014.
24. M. K. Smith, F. H. M. Jones, S. L. Gilbert, and C. E. Wieman, "The Classroom Observation Protocol for Undergraduate STEM (COPUS): A New Instrument to Characterize University STEM Classroom Practices," *LSE*, vol. 12, no. 4, pp. 618–627, Dec. 2013, doi: 10.1187/cbe.13-08-0154.
25. P. Shekhar, M. Demonbrun, M. Borrego, C. Finelli, M. Prince, and C. Henderson, "Development of an Observation Protocol to Study Undergraduate Engineering Student Resistance to Active Learning."
26. L. B. Wheeler, S. L. Navy, J. L. Maeng, and B. A. Whitworth, "Development and validation of the classroom observation protocol for engineering design (COPED)," *J. Res. Sci. Teach.*, vol. 56, no. 9, pp. 1285–1305, 2019. [Online]. Available: https://doi.org/10.1002/tea.21557
27. A. H. Harris and M. F. Cox, "Developing an Observation System to Capture Instructional Differences in Engineering Classrooms," *J of Engineering Edu*, vol. 92, no. 4, pp. 329–336, Oct. 2003, doi: 10.1002/j.2168-9830.2003.tb00777.x.
28. D. Evenhouse et al., "Video coding of classroom observations for research and instructional support in an innovative learning environment," *Australasian J. of Eng. Educ.*, vol. 23, no. 2, pp. 95–105, 2018. [Online]. Available: https://doi.org/10.1080/22054952.2018.1519984
29. National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: The National Academies Press, 2004. [Online]. Available: https://doi.org/10.17226/10999

30. E. Cech, B. Rubineau, S. Silbey, and C. Seron, “Professional Role Confidence and Gendered Persistence in Engineering,” *Am Sociol Rev*, vol. 76, no. 5, pp. 641–666, Oct. 2011, doi: 10.1177/0003122411420815.

Acknowledgments

The authors would like to thank the industrial engineering faculty whose courses were used for analysis in this study. We would also like to thank the college of engineering for their support of this research. This material is based upon work supported by the National Science Foundation Discipline Based Education Research within the ECR-EDU Core Research Program under Grant No. 2054823 and Graduate Research Fellowship Program under Grant No. DGE 1841052. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Appendix: Observation Protocol

Practice	Description	Minutes 0-9	Minutes 10-19	Minutes 20-29	Minutes 30-39	Minutes 40-49	Minutes 50-59
Analyze Data	Interpret data, such as results from modeling, validation, and other data processing		X				
		Description:					
Build Tangible Artifacts	Build tangible artifacts as models, prototypes, or working products (or general mention of tangible products as an emphasis)						
Coding or Programming	Utilizing (or learning about) coding or programming of any form						
Data collection	Follow proper data collection procedures (more research, testing, and/or evaluation purpose)						
Design Experiments	Develop plans and procedures for experiments						
Ethics	Weigh (complex) ethical responsibilities and dynamics in engineering decision making						
Evaluate Solutions	Test and evaluate potential solutions						
Foundational Technical Knowledge	Understand or research fundamental engineering principles or technical knowledge (e.g., mathematics, thermodynamics, statics)						
Future Impacts	Consider or account for potential future impacts of one's work						
Immediate context	Account for the immediate problem context (the space or context in which a solution may be deployed) as it relates to one's work						
Info Gathering & Research	Conduct research or gather information needed to address a problem (at any stage in a problem solving process)						
Innovation	Come up with innovative ideas and approaches for addressing a problem						
Interdisciplinarity	Collaborate across disciplinary boundaries or incorporate ideas and approaches from other fields of study when appropriate						
Interpersonal Awareness	Demonstrate social awareness, empathy, and self-awareness in interactions with others						
Iteration	Iterate on and improve on ideas or designs						
Leadership	Demonstrate leadership to ensure teams work effectively toward common goal						
Logistics	Understand or coordinate logistics of a process/problem/system and organize needed information						
Modeling and Simulation	Develop or work with virtual models or simulations						
Natural Environment	Account for ways natural environment may affect or be affected by one's work or consider issues of sustainability						
Optimization	Use engineering tools or methodologies to make a solution as efficient or effective as possible or identify the best solution						
Predict Outcomes	Draw on science and engineering principles and/or methods to predict outcomes						
Present on or Explain Work	Discuss, present on, or explain work, its value, or otherwise communicate about it verbally (not necessarily technically-oriented communications)						
Problem Definition	Analyze a problem and define the constraints and requirements						
Project Management	Coordinate work process across multiple stages of a project and/or across multiple teams/members						
Relationships and Tradeoffs	Account for relationships or tradeoffs between multiple elements or components of a project and/or the larger system						
Social Context	Account for social or cultural context in which engineering work is embedded						
Stakeholders	Engage with or account for stakeholders in exploring problems and potential solutions						
Teamwork and Collaboration	Collaborate with others by sharing expertise, ideas, resources etc. to achieve a common goal						
Technical Communication	including written and oral reports or use of figures to represent work to an audience						
Technical Details	Account for, develop, or refine the concrete details, design, or schematics of solutions or potential solutions						
Troubleshooting	Systematically identify or assess issues or potential issues in a product, design, or process to ensure it works correctly						
Power/Position/Identity	Consider dynamics related to the identities, posititions, backgrounds, or relative power of self and/or other stakeholders						
Human Factors and Ergonomics	Account for how a range of humans/bodies may physically interact with a given design, product, or process						
Lifecycle of a solution	Consider a design, product, or process over the course of its lifecycle, including considerations of longevity						
Business and Financial	Account for financial or economic considerations (applied or theoretical) to guide decisions						
Other	Another practice not mentioned above						