Developing Engineer Systems Competencies with a Nexus of Engineering, Law, and Policy

Mrs. Sandra Allain, Pennsylvania State University

Professor of Practice in the School of Engineering Design and Innovation in the College of Engineering at Penn State, Lecturer in Law at Penn State Law, and an affiliate of the School of International Affairs and the Sustainability Institute at Penn State. Inaugural Director of the Law, Policy, and Engineering initiative - LPE, and the Design, Justice, and Sustainable Development Lab - DJSD. Over 15 years experience as a practicing attorney in intellectual property and technology transfer in both private practice and as in-house counsel, including in the Office of University Counsel at the University of Illinois. Passionate about education, sustainability, access to justice, equity, diversity, and social justice. Worked in higher education since 2007 in various roles including in-house counsel, tech transfer and innovation, global programs, international partnerships and business development. Research interests include innovation ecosystems, the UN Sustainable Development Goals, public interest technology, community engagement for technology adoption, legal design, legaltech, civic tech, Edtech, Virtual Reality and participatory policy-making. LL.B. Law Degree Universidad del Rosario, Colombia; M.Ed. University of Illinois at Urbana-Champaign; Illinois Board of Admissions to the Bar - License inactive Illinois Supreme Court

Dr. Robert J. Rabb P.E., Pennsylvania State University

Robert Rabb is the associate dean for education in the College of Engineering at Penn State. He previously served as a professor and the Mechanical Engineering Department Chair at The Citadel. He previously taught mechanical engineering at the United States Military Academy at West Point. He received his B.S. in Mechanical Engineering from the United Military Academy and his M.S.E. and PhD in Mechanical Engineering from the University of Texas at Austin. His research and teaching interests are in mechatronics, regenerative power, and multidisciplinary engineering.

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The scope and expectations of the engineering profession are changing swiftly to keep pace with technological and social advancements. Economic and global issues, innovations, expansion of discipline boundaries, and increased professional responsibilities are transforming what engineers do, especially as they progress in their careers. Contemporary engineering challenges and solutions are often multi-disciplinary in nature and require systems thinking in problem formulation and results. The need is apparent for engineers with strong technical knowledge, who can think creatively and critically, communicate effectively, and work in teams. However, the very nature of engineering, as defined by different organizations, points to the coupling of the engineering profession with society. "Engineering is the profession in which a knowledge of the mathematical and natural sciences, gained by study, experience and practice, is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind" [1]. With full undergraduate curricula to meet these technical and early professional competencies, engineers progressing in their careers as executives, analysts, consultants, and advisers will need graduate education to meet increased professional responsibilities. Specifically, these include increased technical, policy and regulatory skills; expanded professional skills; the ability to identify opportunities for improvement; and the ability to work effectively in a globally connected and interdisciplinary work environment. To address the increasing demand for engineering professionals to have advanced education, Penn State University developed a new Master of Engineering degree to prepare STEM professionals who are versed in policy and law systems and the way emerging technologies interact with and enter these systems. The Master of Engineering degree in engineering, law, and policy (MELP) will enhance the key attributes of an engineer: solidly grounded, technically broad, globally minded, ethical, innovative, excellent collaborators, and visionary leaders that excel at delivering impact with social consciousness.

This paper discusses the development of the MELP residential program aimed to provide graduates with a competitive advantage when seeking employment at the nexus of science and technology policy, policy analysis, complex systems design, and regulatory compliance within an engineering systems framework. Qualitative student feedback is also discussed, showing the positive impact of the new MELP courses developed.

Introduction

The National Academy of Engineering (NAE) has recognized the need for engineers to work on interdisciplinary teams. Rapid advances in technology and globalization have spotlighted the need for engineers to engage in policy and law [2]. The NAE stated, "…*consideration of social issues is central to engineering. Political and economic relations between nations and their peoples will impact engineering practice in the future. Attention to intellectual property, project management, multilingual influences and cultural diversity, moral/religious repercussions, global/international impacts, national security, and cost-benefit constraints will continue to drive engineering practice*." The NAE also remarked that engineering problems to be solved might require synthesis of a broader range of interdisciplinary knowledge and a greater focus on systemic constructs and outcomes [3].

The need for engineers to have broader skills and knowledge in policy and law is echoed in engineering disciplines. The ASME Vision 2030 [4] states that the problems for mechanical engineers require systems thinking in problem formulation and solution, and asserts that we must educate engineering students for an era of increased scope, scale, and complexity. There needs to be development of skills in engineering graduates that will produce the engineering leadership required for implementing the technology and policy to solve the challenges facing their companies, regions, and the planet and graduates who are involved in policy decisions at many levels of society. Expertise in law and policy will be required to a much larger degree in accelerated product development. Topics such as these are typically not a significant part of the mechanical engineering curriculum.

According to ASCE Vision 2025 [5], an aspirational target for civil engineers is for them to be masters and leaders in shaping public policy, where "master" implies "leader" in both role and knowledge. The Vision further expands that their role as public policy leaders, civil engineers will possess the skills for broad-based policy discussions. Civil engineers must be given the tools and training for engagement in public policy work, while they become more vocal participants in public policy forums. Additionally, the discipline suggests that we must expand opportunities for life-long education on public policy topics so that civil engineers will be better prepared to participate in these discussions.

Even with evidence cited in the vision papers from the NAE and specific disciplines, there still exists a lack of teaching and learning opportunities to address this gap.

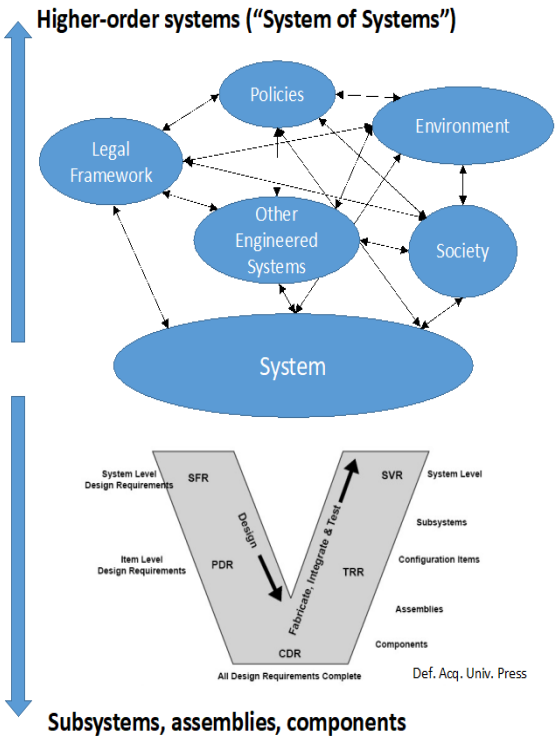
Background

Included in the vision of the University's strategic plan is the aspiration to impact the world through solutions-oriented approaches to major societal issues. The university recognized a need for an interdisciplinary approach as many of the solutions lie at the interface between law, policy, and engineering. The University established the Law, Policy and Engineering (LPE) initiative in 2018 to foster collaboration between of the College of Engineering, the Law School, and the School of International Affairs. A result of this initiative was the design and approval to begin a Master of Engineering (M.Eng) degree in Engineering, Law, and Policy (MELP). This degree is designed to address some of the shortfalls in the STEM workforce and foster innovation, public interest in technology[6], science and technology policy, and regulatory science. MELP is a one-year residential 30 credit full time non-thesis master's degree that provides training for advanced professional practice [7]. The MELP program is for students looking to position themselves in policy and regulatory roles to drive responsible innovation and serve society at large. They will acquire the tools and interdisciplinary skills needed to navigate today's rapidly evolving technology-driven and datadriven workforce, with practical understanding of the regulatory and policy frameworks surrounding emerging technologies and how policymaking takes place.

Within MELP's 30 credits, there are 9 credits of electives and 21 credits (seven required courses of 3 credits each), as follows:

• INTAF 502 Science, Technology, and International Policy: Examines science and policy communities, the importance of science and technology to international affairs, scientific issues likely to affect international policy.
• EDSGN 549 Design Decision Making: Complexity of design-making; state-of-the-art methods and tools. Information and decision making in design; understanding the complexities due to uncertain information, multi-person decision making, technology obsolescence, and competing priorities.
• EDSGN 558 Systems Design: System engineering principles and practices and the application of systems engineering in the analysis, design, development, integration, verification, and validation of complex systems.
• LPE 851 Foundations in Public Law : A foundation course for engineers and other non-law graduate students on how public law regulates engineering, science, and technology policy; how the executive, legislative, and judicial branches of government interact to form science and technology policy, how administrative agencies and regulations implement that policy, and how the judicial review of legislation and regulation affects policies, regulations, and systems.
• LPE 852 Foundations in Private Law: A foundation course for engineers and other non-law graduate students on how engineering, science, and technology is affected by private law; including employment/labor, mergers and acquisitions, antitrust, intellectual property, torts, financial instruments, fiduciary duties, and criminal law.
• LPE 853 Engineering, Law and Policy Systems: An interdisciplinary course providing a broad exploration of the relationship between engineering, policy, and law. From driverless cars to AI-powered systems, engineering is transforming public and private spaces. This course identifies the legal and political constraints engineering solutions
must satisfy to be implemented within complex engineering systems.
• LPE 854 Engineering, Law and Technology Policy Practicum: This course addresses current pressing issues in innovation, technology policy, and law through the eyes of policymakers. Students work on public-facing projects in interdisciplinary teams applying strategic technology policy, regulatory concepts, and systems thinking to realworld policy issues to assist relevant policymakers in their policy decision-making process.

Through the application of engineering systems principles (Figure 1), the use of systems design, and an understanding of sociotechnical systems, students in the MELP program will acquire the knowledge necessary for the understanding of policy and law as a system and how law, policy, and technology converge. Students will also develop skills for the analysis of complex systems problems, characterized by multi-stakeholder engagements reflecting the complexity of the stakeholders, the evolving and interactive norms, and resources involved. These complex systems can include local, state, and federal interdependencies and/or global interdependencies that require examination from a systemic and governance approach. These are common in areas of public planning, international affairs, and policymaking relying heavily on modeling that employs innovative methods for actual implementation.



Engineering Systems: Class of systems characterized by a high degree of technical complexity, social intricacy, and elaborate processes, aimed at fulfilling important functions in society

System: Group of interacting or interrelated entities that form a unified whole. Delineated by spatial and temporal boundaries, surrounded and influenced by its environment, described by its structure and purpose, and expressed in its functioning

Systems Engineering: Transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods (INCOSE)

Figure 1. Engineering Systems, Bilen, S.,2020

With the increasing rate of technological innovation and convergence among technologies and systems—such as Industry 4.0; energy and communication systems; the digitalization of industry through automation, machine learning, and artificial intelligence, among others—unprecedented political, ethical, economical, legal, and social implications emerge. These result in new opportunities as well as risks. The MELP program will prepare the next generation of engineers versed in policy and law systems and in the way emerging technologies interact with and enter into these and other existing systems. Students will be able to analyze and influence legislative developments and policy initiatives and anticipate technology trends.

Expansion of the Program

The MELP program was approved by the Graduate School in May 2021 and accepted its first students in Fall 2022. It was approved as a residential program and only offered in face to face modality. This advanced professional program is flexible. It was designed to work with students on their timelines and can be completed in two semesters of intensive study, one year of full-time study, or two years of part-time study. With no thesis or research requirement in the MELP degree, a logical expansion of the degree is to offer it remotely or in hybrid. The Outreach Marketing and Market Research (MAMR) at Penn State was consulted to provide an assessment of the potential market for online delivery.

Target Audience

MAMR identified a target audience for this program of 35 occupations and over 3.2 million workers including engineers, compliance officers, analysts, scientist, and STEM managers. They acknowledged that this total likely included a large number who were not in roles related to MELP and may not be interested in the MELP program. However, employment among the target occupations is projected to grow 9% by 2031, which is slightly above the 8% national average for all occupations (Table 1). The top six employing occupations account for over half of the workers in the target audience: compliance officers, civil engineers, mechanical engineers, industrial engineers, architectural and engineering managers, and electrical engineers [8].

Table 1: Target Occupations

Worker Employment in Target Occupations			
2021	2031	Change	% Change
3,230,624	3,522,544	291,920	+ 9%

Approximately 1.5 million workers in the target occupations have a bachelor's degree as their highest level of education and would be the most likely source for a master's degree in MELP. However, it is difficult to determine what portion of the target audience would pursue the MELP degree. Depending on the worker's career aspirations, they may be more likely to pursue a master's degree in business, engineering management, or a specific engineering or science discipline. Nearly 1.1 million workers already hold a master's degree or higher and may be less likely to pursue a second master's degree. If these workers are interested in MELP content, they may seek shorter credentials, such as certificates or noncredit offerings [9].

To better understand demand in the labor market, MAMR used a job posting analytics tool from the economic modeling software, Lightcast. This tool reviews relevant websites (e.g., governmentjobs.com, careerbuilder.com), to compile job posting data. Between February and July 2022, there were approximately 1.33M unique job postings for workers in the target audience. However, skills relating to law, policy, systems thinking, or regulatory affairs were not commonly listed in the postings. Most of the openings were engineering or IT related positions, with employers typically seeking early career candidates with bachelor's degrees. Job postings that required or preferred candidates with master's degrees accounted for approximately 23% of the postings. These positions were typically analysts, engineers, or managers in STEM roles. An MBA degree was among the top qualifications preferred for hiring. Approximately 33,000 unique postings specifically mentioned regulatory or policy-related skills. Most of the job postings were in the manufacturing and professional, scientific, and technical services sectors. Figure 2 graphically shows this down selection of the target audience [10].

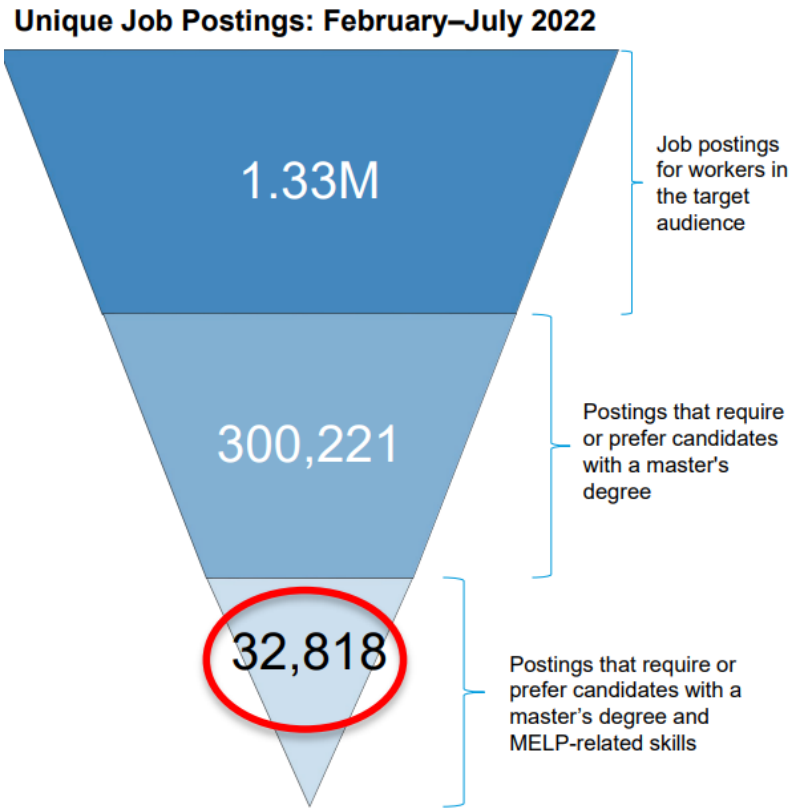


Figure 2: Job Postings

Based on the job postings, employers typically required candidates to possess the following knowledge, skills, and abilities:

- Education: bachelor's degree required; master's degree preferred. While many employers did not specify the field of study, the MBA was the most frequently mentioned degree qualification.
    - For workers in the IT sector, it was also common for employers to require additional industry certification.
- Experience: 4-10 years.
- General skills: regulatory compliance/requirements/affairs, policy development, new product development, risk analysis/management, process analysis, project management.
- Sector-specific skills: cybersecurity, information system privacy/security, medical devices, clinical research/trials, manufacturing process/improvement, automation.

Table 2 highlights potential employeers and job titles

Table 2. Potential Employers for MELP Graduates [12]

Potential Employers	Sample Job Titles
Federal Government (Executive branch): Census Bureau, Department of Agriculture, Department of Defense, Department of Health and Human Services, Department of Energy, Department of Homeland Security, National Institute of Justice, Department of State, Fish and Wildlife Service, National Aeronautics and Space Administration, Environmental Protection Agency, National Institutes of Health, National Institute of Standards and Technology, National Science Foundation, US Agency for International Development, Citizen and Immigration Services, U.S. Food and Drug Administration, Nuclear Regulatory Commission, National Council of Aging, Veterans Health Administration, National Nuclear Security Administration, Federal Aviation Administration, and the White House Office of Science and Technology Policy, among others	• Regulatory Affairs Specialist / Associate • Regulatory Affairs Manager / Director • Compliance Officer • Clinical Research Coordinator • Information Systems Security Officer / Manager • Risk / Compliance Analyst • Environmental Planner / Scientist / Engineer • Regulatory Specialist • Principal Engineer / Scientist • Process Engineers • Regulatory Analyst • Product Development Manager • Quality Control Engineer • Research Scientist / Engineer
Federal legislative support offices such as the Congressional Research Services; Library of Congress; Congressional Committees: i.e. Education and Labor; Energy and Commerce; Natural Resources; Science, Space and Technology; Transportation and Infrastructure; Agriculture, Nutrition and Forestry; Commerce, Science and Transportation; Energy and Natural Resources; Environment and Public Works; Health, Education, Labor and Pensions	
State government and legislatures	
Nonprofit Organizations and Foundations, International Organizations, Think Tanks, Lobbying Firms, Consultancy Firms, Professional Associations, and Law Firms with a science/technology policy nexus	

Discussion

The target audience for the proposed MELP degree includes approximately 1.5 million workers in STEM related roles who currently hold a bachelor's degree as their highest level of educational attainment. However, it is unclear how many of these workers will need the in-depth law, policy, systems thinking, and regulatory knowledge provided in the proposed program.

While regulation and policy content is valued by some employers, it is not a primary focus of most workers in this audience. The target audience is split between workers who need broader legal training to understand and comply with legal/policy requirements and workers in specialized fields where industry-specific knowledge of regulatory and policy issues is critical. Both of these audiences would benefit from the engineering systems mindset and competencies provided by MELP. Unfortunately these qualifications are not always required or cited in job descriptions.

Engineering Systems Framework

Systems thinking is essential for engineers in order to understand how systems work and the factors influencing the function of the system [13], it is a framework necessary to understand complex problems, which are frequently those at the intersection of law, policy, and engineering. MELP's learning outcomes highlight that students will acquire the skills to develop solutions to complex societal problems by applying systems thinking and principles of engineering system and integrating perspectives from law, policy, engineering, and ethics. The MELP degree accomplishes this by having students take a course in "Systems Design", and the development of a new course "Engineering, Law, and Policy Systems", both which are described below.

Systems Design, and Engineering, Law, and Policy Systems examine the role components play within systems, the optimization of systems as a whole, and design decision-making. This also includes the understanding of complex systems of systems (Figure 1), where perspectives from economics, law, policy and management are combined with engineering in order to address the design and development of the complex, large-scale, sociotechnical systems present in modern society. The depth and breadth of competencies, often based on domain specific technical background, are expanded to support new interdisciplinary roles and positions within management, policymaking, research development, and consultancy.

- **LPE 853 Engineering, Law and Policy Systems**: An interdisciplinary course co-taught between the School of Engineering Design and Innovation and the Law School, providing a broad exploration of the relationship between engineering, policy, and law. From driverless cars to AI-powered systems, engineering is transforming public and private spaces. This course identifies the legal and political constraints engineering solutions must satisfy to be implemented within complex engineering systems.
- **EDSGN 558 Systems Design**: The course is designed to immerse students in the principles, practices and application of systems engineering within the design, development, integration and deployment of complex systems. Students will learn the special functions and responsibilities of systems engineers in comparison to analysts, design specialists, test engineers, project managers and other members of the systems development teams. They will acquire the knowledge, skills and mindset necessary to be successful as part of a major system development project and will acquire the leadership, problem-solving and innovation skills necessary for success.

Student feedback obtained from MELP's first cohort is a small sample of the potential impact of this degree. When asked, what aspects of this course helped you learn, students replied:

"Helped me broaden my understanding of systems in policy making. Was introduced to a lot of literature that went through the various challenges of systems thinking as well."

"Helped me understand the contours of American law and public policy making."

"Group discussion with a class who was very involved in the course gave us several perspectives".

"The course had interesting projects that helped develop good manufacture and research skills. Improved my writing style and learnt correct scientific writing methods."

"The course stands great as it is. Loved the readings that were provided and the project exercise to create a law, policy, and engineering system."

Conclusion and Future Work

It is important to emphasize the partnership between engineering, law, and policy for the future STEM workforce and acknowledge the collaboration between of the College of Engineering, the Law School, and the School of International Affairs to design, develop and implement a Master of Engineering (M.Eng) degree in Engineering, Law, and Policy (MELP). The program is designed to develop the attributes required by today's successful engineering executives, analysts, consultants and advisers. Specifically, these include increased technical, policy and regulatory skills; expanded professional skills, including an engineering systems mindset; the ability to identify opportunities for improvement; and the ability to work effectively in a globally connected and interdisciplinary work environment.

Next steps in the program include exploring the application and assessment of the INCOSE sociotechnical systems engineering competency framework [14]. The framework provides a set of 36 competencies for systems engineering, which emphasizes societal considerations. In addition, the program will build an outreach strategy to help communicate the value of this innovative degree with both internal and external stakeholders. Given the nature of this new degree, work needs to be done to position MELP as a frequent degree qualification preferred by employers, such as the status that an MBA degree holds. Both degrees serve different purposes and provide different skills, however in today's world driven by digital transformation and emerging technologies, law and policy competencies for technologists, scientists, and engineers are not just an added value. Understanding, analyzing, communicating, and leading issues and policies at the intersection between technology, law, and policy is a necessity to foster innovation, create new business value, and remain competitive in global markets.

An additional line of effort will be to avail portions of this program remotely. There are few direct competitors in the online market. As a lower financial risk to the full degree, the college should consider collaborating with other academic units to incorporate content from the proposed degree into programs targeting a similar audience with similar or related content. This would limit development of multiple programs targeting this same audience. Academic partners could also consider the development of one to two online MELP-related electives that would add further value to other existing or proposed online graduate-level programs. Other extensions and

outreach can include micro-credentials and certificates as we move the forward to be relevant to the engineering workforce and disciplines.

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