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A Systematized Literature Review on Workforce Development Programs for Engineering Graduate Students

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The State of the Art of Workforce Development for Engineering Graduates

Abstract:
Ph.D. graduate students in engineering are being hired by industry at higher rates compared to institutions of higher education. Despite this industry preference, higher education institutions, which traditionally prepare graduate students, are not equipping Ph.D. engineering students to transition to the workforce. Therefore, to better prepare our engineering graduate students, we must start by understanding the current state of Ph.D. professional preparation programs in both industry and academia. This exploratory study's purpose was to scope existing peer-reviewed and published articles describing the focus and target audience of engineering workforce training programs for graduate students in industry and academia. The study aimed to explore what existing workforce trainings exist for graduate engineering students and then, to see what skills they are teaching students. The objective was to, using the information from the scoping review, to begin to outline workplace reading skills and criteria for a future development of a theory of workplace readiness for Ph.D. engineering graduate students. This exploratory study used the Virginia Workplace Readiness skills framework to classify the skills provided to participants of these workforce development programs. The research questions (RQs) for this study were: (RQ1) What training programs exist in the literature for workforce development for engineering Ph.D. students? (sub-RQ1) How are Ph.D. workforce training programs for engineering graduate students in the literature being described? (RQ2) What workforce readiness skills do these training programs have for engineering Ph.D. students and how do they align with the type of skills described in the Virginia Workplace Readiness skills framework? To address these research questions and sub-research questions, we performed a systematized literature review utilizing three databases: SCOPUS, Engineering Village and ERIC. The selection of the databases was based on our goal to synthesize education-related literature within engineering by structuring a search that yields multidisciplinary results. The systematized literature review included an initial screening of 567 abstracts and resulted in the synthesis of 23 papers. We identified the characteristics and common goals of these programs. The workforce training programs were classified into three themes: (1) personal qualities and abilities, (2) interpersonal skills, and (3) professional competencies.

The findings shed light into: (1) the need to prepare engineering Ph.D. students in professional skills, given its lack of mention in workforce training programs; (2) the efforts that have gone into preparing engineering Ph.D. students in cutting-edge technical topics; and (3) highlighting the need to increase participation of industry in professional training of graduate students.

Introduction and background:

Workforce development for graduate students is a subject of considerable research, yet preparing graduate engineering students for workplace success remains a challenge for universities. According to the U.S. Bureau of Labor Statistics, 188,000 openings for architecture and engineering occupations and 377,500 openings for computer and information technology occupations are projected from 2022 to 2032, with little information as to whether these positions will be filled by then [1][2]. In order to contribute to students' individual career success and broader societal advancement, workforce development programs are essential for: (1) skill enhancement, (2) industry demands, (3) increasing employment rates, and (4) global competitiveness. These aspects are contributing factors in the increased need for a skilled engineering workforce.

Recent trends show that Ph.D. graduates are being employed more by private sector companies compared to academia [3]. From 1997 to 2017, engineering Ph.D. graduates who later worked as faculty in academia and who held a tenured or tenure track position dropped from 23% to 16% [3]. Similarly, math and computer science has seen a decrease in post-Ph.D. faculty holding a tenure or tenure track position after graduating from 49% to 33% [3]. In 2017, a survival analysis of faculty retention was performed across 14 U.S. universities on 2,966 individual faculty assistant professors in science and engineering who were hired since 1990 [4]. Results showed that the retention probability of any given faculty member in science and engineering departments over time was less than 50% [4]. Additionally, the median departure time was 10.9 years after entering the academic workforce as an assistant professor [4]. Due to the declining trend that U.S,- trained Ph.Ds. are less likely to secure a faculty position, universities began to collect data on the career outcomes and started assisting science and engineering graduate students in obtaining internship and networking opportunities [3].

Out of the instruments reported in the literature around workforce skills development, *The Global Set of Mutual 24 Skills* and the *Virginia Workplace Readiness Skill* are the most comprehensive. While these frameworks have been developed to outline a number of skills engineers need in the workplace [5][9], less is known about programs and initiatives that target Ph.D. engineering students' workforce readiness skills. For this paper, we will evaluate the following research questions:

RQ1: *What training programs exist in the literature for workforce development for engineering graduates?*

> *Sub-RQ1: How are Ph.D. workforce training programs for engineering graduate students in the literature being described?*

RQ2: *What workforce readiness skills do these training programs have for engineering graduates and how do they align with the type of skills described in the Virginia Workplace Readiness skills framework?*

Framework: Workplace Readiness Skills [5]

The Virginia Workplace Readiness Skills framework was developed at the Weldon Cooper Research Center at the University of Virginia to identify specific skills essential for employee success. Having been in effect for more than 25 years, this framework has been implemented into the curriculum of every state Career and Technical Education (CTE) course to create a symbiotic relationship between employees and employers. The target population of the Commonwealth Workforce Readiness Skills were entry-level employees who can now earn graduation credit and a digital badge by passing the *Workplace Readiness Skills for the Commonwealth Assessment Examination* that covers the respective 21 skills. The skills are continuously updated to incorporate relevant trends that can influence the needs and skill demands of the workplace. These trends include: the information revolution, automation, globalization, rapid and continuous innovation, organizational restructuring, and time-and-power shifting.

For the development of the Virginia Workforce Readiness skills framework, a total of 400 Virginia employers responded to the Weldon Cooper Research Center survey from June 19 to August 9, 2017, asking to rate the importance of workplace readiness skills for entry-level workers to investigate any gaps in Virginia's workforce. Of these 400 employees, 16 are from engineering fields. The current workforce readiness skill domains of this framework include (1) personal qualities and people skills, (2) professional knowledge and skills, and (3) technological knowledge and skills. There were seven workforce readiness skills denoted by the majority of employers as "extremely important": initiative and self-direction, integrity, positive work ethic, reading and writing, speaking and listening, teamwork, time, tasks, and resource management. Additionally, the workforce readiness skills that most need improvement were critical thinking and problem solving, positive work ethic, initiative and self-direction, time, task, and resource management, speaking and listening, conflict resolution and customer service. It was recommended that the skill domains be updated to include (1) personal qualities and abilities, (2) interpersonal skills, and (3) professional competencies. Each domain contains a set of skills that align with it; combined these domains have 22 skills that employers seek when hiring.

Table 1. Workplace Readiness Skills framework domains, skills and definitions. Adapted from Virginia Workplace Readiness skill framework [5]

Workforce Readiness Skills	Definition
Personal Qualities and Abilities	1. Creativity and Innovation: Employs originality, inventiveness, and resourcefulness in the workplace. 2. Critical Thinking and Problem Solving: Uses sound reasoning to analyze problems, evaluate potential solutions, and implement effective courses of action. 3. Initiative and Self-Direction: Independently looks for ways to improve the workplace and accomplish tasks. 4. Integrity: Complies with laws and workplace policies; demonstrates honesty, fairness, and respect. 5. Work ethic: Consistently works to the best of one's ability and is diligent, dependable, and accountable for one's actions.
Interpersonal skills	6. Conflict resolution: Negotiates diplomatic solutions to interpersonal and workplace issues. 7. Listening and speaking: Listens attentively and asks questions to clarify meaning; articulates ideas clearly in a manner appropriate for the setting and audience. 8. Respect for diversity: Values individual differences and works collaboratively with people of diverse backgrounds, viewpoints, and experiences. 9. Service Orientation: Anticipates and addresses the needs of customers and coworkers, providing thoughtful, courteous, and knowledgeable service. 10. Teamwork: Assumes shared responsibility for collaborative work and respects the thoughts, opinions, and contributions of other team members.

Professional competencies	11. "Big picture" Thinking: Understands one's role in fulfilling the mission of the workplace and considers the social, economic, and environmental impacts of one's actions. 12. Career and Life Management: Plans, implements, and manages personal and professional development goals related to education, career, finances, and health. 13. Continuous Learning and Adaptability: Accepts constructive feedback well and is open to new ideas and ways of doing things; continuously develops professional skills and knowledge in order to adjust to changing job requirements. 14. Efficiency and Productivity: Plans, prioritizes, and adapts work goals to manage time and resources effectively. 15. Information Literacy: Locates information efficiently, evaluates the credibility and relevancy of sources and facts, and uses the information effectively to accomplish work-related tasks. 16. Information Security: Understands basic internet and email safety and follows workplace protocols to maintain the security of information, computers, networks, and facilities. 17. Information Technology: Maintains a working knowledge of computers, software programs, and other IT devices commonly found in the workplace. 18. Job-Specific Tools and Technologies: Knows how to select and safely use industry-specific technologies, tools, and machines to complete job tasks effectively. 19. Mathematics: Applies mathematical skills to work tasks as necessary. 20. Professionalism: Meets organizational expectations regarding work schedule, behavior, appearance, and communication. 21. Reading and Writing: Reads and interprets workplace documents and writes effectively. 22. Workplace Safety: Maintains a safe work environment by adhering to safety guidelines and identifying risks to self and other.

The Virginia Workforce Readiness skills framework offers a holistic view of the type of skills that employers look for in their current and future workforce. Although it was not developed specifically for engineering or graduate students, it is prevalent to give us some initial insights of current programs and initiatives reported in the literature.

Methodology

This exploratory, multi-method study applied a systematic literature review that applied *a priori* coding based on the skills outlined and defined in Table 2 to reduce bias in the findings. The methods described below were designed to be both repeatable and transparent. While not typical, the authors deemed that transparency, even in the systematic literature review process, cannot be disassociated from the author's positionalities as these informed the selections and procedures to minimize said biases.

Positionality

In relation to this study, the first author is a doctoral student in Engineering Education with a background in chemistry and chemical engineering. Having worked in industry herself as an engineering intern, she saw a need for advancing the workforce development skills in novice engineers who are transitioning to the industrial workforce. Therefore, the approach taken in this study was influenced by the first-hand knowledge and experience of the first author. The second and third authors are both researching professors at R1 universities whose backgrounds are in computer science and chemical engineering along with engineering education and industrial experience. All authors are pragmatists when it comes to engineering education research and stand in agreement with the importance of an integrated engineering skillset and a holistic understanding of the usefulness and applicability of the research findings related to workforce development programs for engineering graduate students. All authors discussed the findings to ensure accountability and minimize bias in the systematic literature reviews conducted.

Methods:

To answer the research questions, a systematized literature review was performed by utilizing a modification of the Kitchenham and Bacca method [7]. This specific method provided guidelines on how to perform a rigorous, three-phase review of current empirical evidence [11] and offers a comprehensive understanding of workforce development programs for engineering graduate students and a better understanding of the current state of knowledge [8]. Due to the robust and transferable nature of a systematic review, research phenomena can be analyzed across a wide range of landscapes and empirical methods [7]. Additionally, applying systematized methods to a large literature view reduces the potential of excluding literature that appears last [7][8]. This approach can then reveal potential gaps in existing literature by providing a higher level of empirical evidence when compared to individual studies [8]. The Kitchenham and Bacca method divides this process into three segments: planning, conducting, and reporting results [8]. In the planning phase, the main objectives were to identify the need for a review in graduate engineering workforce development, develop research questions, select databases to perform the literature search on and define inclusion/exclusion criteria. By using a Prisma diagram, a detailed account of the literature throughout the systematized literature review process was created.

In the second part of the planning phase, the development of a review protocol, the inclusion and exclusion criteria were defined. After the initial search, abstracts were retrieved and then evaluated. The criteria to evaluate the relevance of the article at the abstract level was: (1) population targeted is post-graduates (2) mention of workforce development program (3) a program based in the United States (4) eliminate book reviews, non-peer reviewed papers, talks, technical reports, and datasets (5) only consider papers published since 2020. All post-graduated regardless of their degree and years' post-graduation were included at the abstract level to yield a broad literature search that can later be narrowed down by additional exclusion criteria at the full paper level and to not potentially exclude any articles relevant to the literature review.

Researchers utilized a working definition of the term "workforce development" to refer to any program that was preparing students for the workforce. Additionally, to maintain a focused scope, only peer-reviewed journals and conference papers were included. However, in the future, we plan to examine all available sources of literature. Considering the shifts in the engineering workforce practices due to the COVID-19 pandemic, this literature search was limited to sources published post-2020. This timeframe was chosen to accurately reflect the current state and needs of the workforce, which has increasingly adopted hybrid and remote working modalities. Microsoft Teams (Version 1.6.00.35956) and Zotero (Version 6.0.30) were used, and three databases were selected (SCOPUS, Engineering Village, and ERIC) to yield multidisciplinary peer-reviewed research papers with a focus on education and specialized engineering content.

Table 2. Query syntax used to search databases for literature and the number of resulting papers

Database	Syntax	Resulting papers
SCOPUS	(TITLE-ABS-KEY (engineer*) AND TITLE-ABS-KEY ("workforce development" OR "technical education" OR " technical skill" OR "technical skills" OR "technical skillset") AND TITLE-ABS-KEY (learning AND assessment OR educational AND assessment OR training)) AND (LIMIT-TO (AFFILCOUNTRY , "United States")) AND (LIMIT-TO (SUBJAREA , "CENG") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "MATH") OR LIMIT-TO (SUBJAREA , "COMP")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (DOCTYPE , "cp"))	122
Engineering Village	((((((engineer*) WN KY) AND (("workforce development" OR "technical education" OR " technical skill" OR "technical skills" OR "technical skillset") WN KY)) AND ((learning AND assessment OR educational AND assessment) WN KY)) AND (English WN LA)) AND (({united states} WN CO) AND (({ca} OR {ja}) WN DT) AND ({english} WN LA)))	401
ERIC	((ALL=(engineer*)) AND ALL=("workforce development" OR "technical education" OR " technical skill" OR "technical skills" OR "technical skillset")) AND ALL=(learning AND assessment OR educational AND assessment)	44

A hard search was performed on each database with its corresponding syntax query (see Table 2) for published abstracts of papers that were peer-reviewed and published. After the evaluation at the abstract level, the full articles corresponding to the abstracts selected were evaluated. After examining the abstracts, additional inclusion/exclusion criteria for the full paper analysis contained the following aspects: (1) program must not be a curriculum, degree seeking program, poster, roadmap, or exam, and (2) target population must be relevant to engineering field. Final inclusion and exclusion criteria (Table 3) were made after the full texts were reviewed. Microsoft Teams was then utilized to label, download, and store each research paper. This was the syntax developed for the organization of the digital files:

[last_name_author]_[topic]_[conference_or_journal]_[year]

Table 3. Summary of the inclusion and exclusion criteria used throughout the systematized review

Phase	Inclusion Criteria	Exclusion Criteria
Abstract Review	1. Population targeted is post-graduates 2. Mention of workforce development program 3. A program based in the United States 4. Eliminate book reviews, non-peer reviewed papers, talks, technical reports, and datasets 5. Work-in progress articles 6. Only consider papers published since 2020	1. Population targeted are K-12 students or undergraduates 2. Does not mention workforce development program 3. Literature is non-peer-reviewed
Full-paper Review	1. Target population must be relevant to the engineering field	1. Program must not be a curriculum, degree seeking program, poster, roadmap, or exam

Data synthesis and monitoring were performed using Microsoft Excel. To optimize the data synthesis and monitoring process, categories to identify characteristics and skills being taught in each program were used. These categories were: (1) online or in-person, (2) type of program, (3) topic, (4) target population, (5) duration, (6) objective, (7) skills provided, (8) target industry, (9) activities, (10) justification, and (11) funding source. Further assessment was conducted on the targeted skills because of the wide range of skills provided in these workforce development programs. Then, *a priori* coding was performed so that every workforce readiness skill could be categorized utilizing the Virginia Workforce Readiness framework specific skills definitions. Afterwards, by applying the Virginia Workforce Readiness Skill framework created by the Weldon

Cooper Research Center of University of Virginia, a priori coding was performed to categorize the skills found in the workforce development programs into the three domains proposed [9]. Utilizing the specific definitions outlined in the framework, the skills were matched to their respective category in the final stage, the results are communicated using descriptive tables and descriptive statistics.

Limitations:

Although this paper paints an initial landscape into the workforce readiness skills of engineers in industry, it is limited because many companies do not disclose training or workshop information which limits the studies included. Additional limitations of this systematic literature review included: (1) the *Virginia Workplace Readiness Skill* framework was not developed specifically for engineering graduate students, (2) the literature search was limited to three databases, (3) the research articles presented may not reflect all the work and research performed informally and not published, (4) the Kitchenham and Bacca method for systematic literature review does not address the effects that various types of systematic review questions have on systematic review procedures, (5) industry training programs are not likely to publish peer reviewed studies on their in-house workforce training programs, (6) massive open online courses (MOOCs) are also unlikely to publish peer reviewed studies because of the large volume of students, (7) there is not concrete definition of what a "workforce training program" is and (8) the quality of the identified papers for this literature review included was not assessed; therefore, any literature that met our qualifying criteria was included in this literature review [7]. In the future, we plan to develop a workforce readiness skills framework for engineering graduate students and a framework for skills that outline workforce training frameworks Additionally, further assessment will be performed on engineering graduate students and how prepared they are to transition to the workforce.

Authors' acknowledgment:

The first author of this article oversaw refining the database queries and the retrieval of the information from each database. In addition, they led the efforts on organizing the information and coordinating with the second author on the priori coding of each article. The second author guided the methods, participated in the data collection along with the analysis and discussion of results. The third author linked the results to the research to practice. In addition, all three authors worked together in forming the research questions and justification of the research.

Results:

RQ1: What training programs exist in the literature for workforce development for engineering graduates?

As shown in Figure 1, from the systematized literature review, 567 papers were retrieved from three databases: SCOPUS, Engineering Village, and ERIC. Eighty duplicate papers were eliminated, and 487 papers were included in the abstract-level review, out of which 403 papers were eliminated after taking into consideration the inclusion and exclusion criteria. Consequently, 84 papers were found eligible for the established criteria. During the full paper review, three additional papers were eliminated as they were not available through the institution's database. From the literature search, 23 training programs that aimed to train engineering graduates for the workforce were found in the literature. The summary of the programs, names, and identifiers along with the corresponding papers can be found in Appendix A.

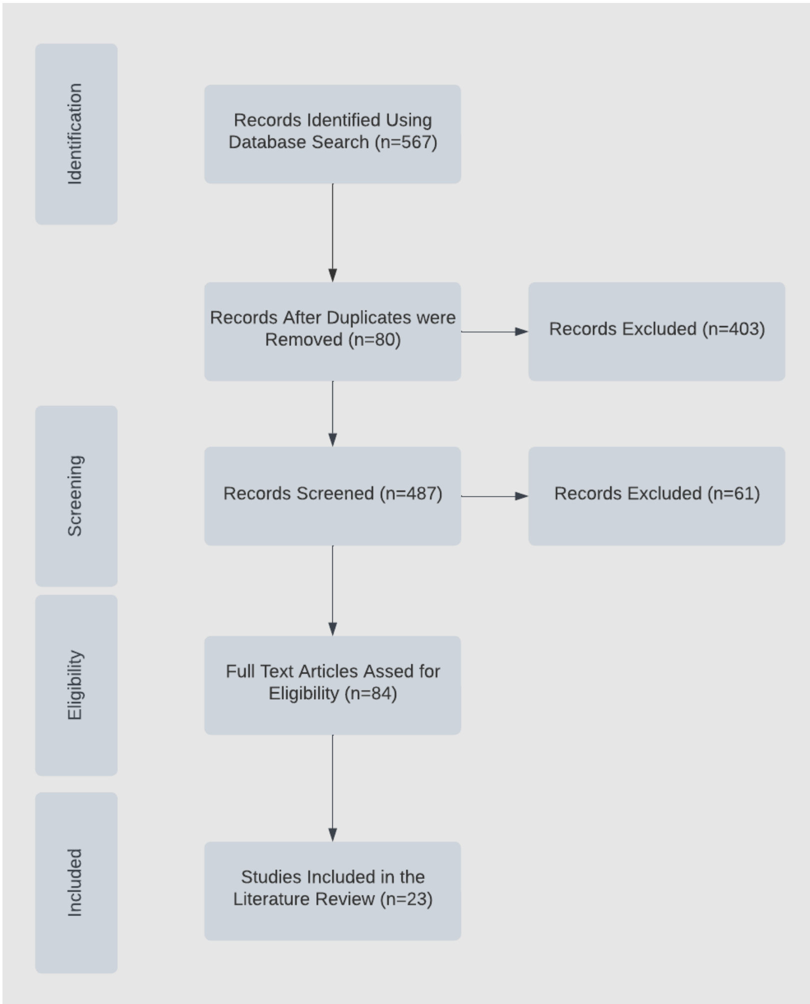

Figure 1: Prisma diagram showing the number of records kept at each step of the literature review [10]

Sub-RQ1: What are the characteristics of these workforce training programs?

As shown in Figure 2, 65% of the workforce development programs were in-person (n=15), 22% were online (n=5), and 13% were hybrid (n=3). These workforce development programs were categorized by program type. Among the 23 workforce development programs, there were 2 bootcamps, 2 case studies, 2 certificates, 1 developing workforce training program, 9 workforce training courses, and 6 workshops. It is important to note the interchangeable use of the terms "boot camp" and "workshop". These terms were often used interchangeably, and we were unable to find a definition or trend of what the characteristics of a "workshop" versus a "boot camp" were, thereby creating confusion when trying to categorize the workforce development programs. For example, STEM Manufacturing industry, the Online Model-based Systems Engineering (MBSE) Bootcamp was online and lasted for two days, whereas the Leveraging MOOCs in a Hybrid

Learning Bootcamp Model for Training Technicians and Engineers in STEM Manufacturing was hybrid and did not have a specified duration. Nonetheless, the self-description made by the authors in the article was the category kept for categorization.

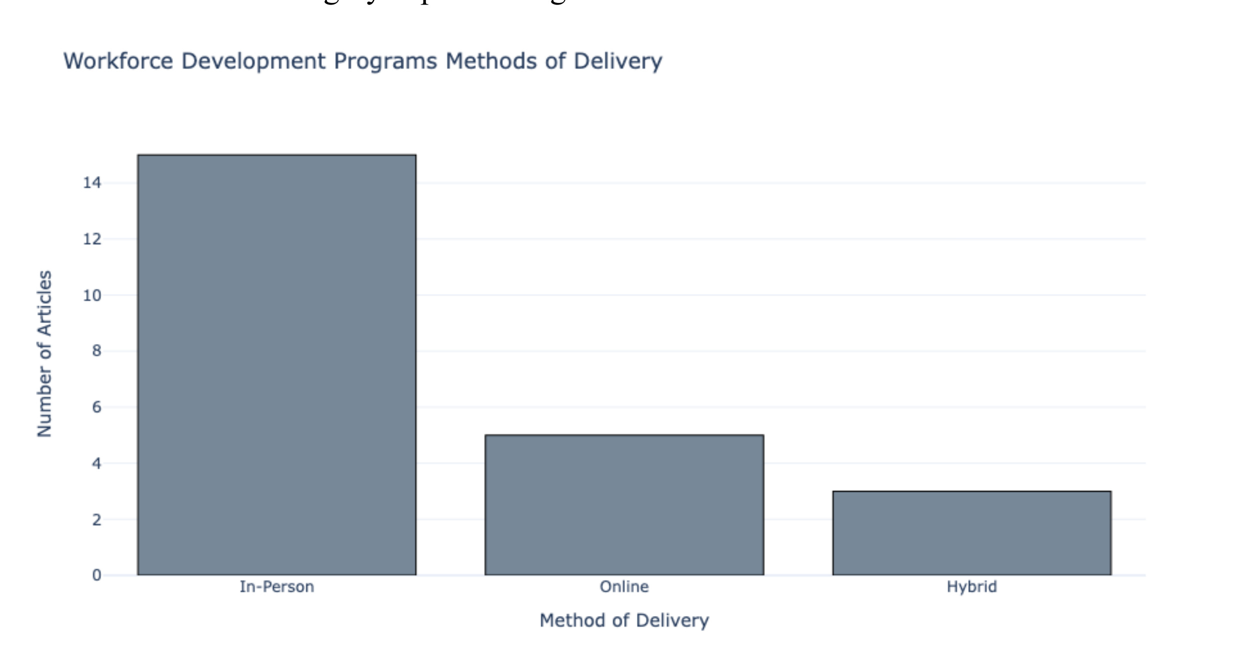

Figure 2: Comparison of workforce development programs that are in-person, online, or hybrid.

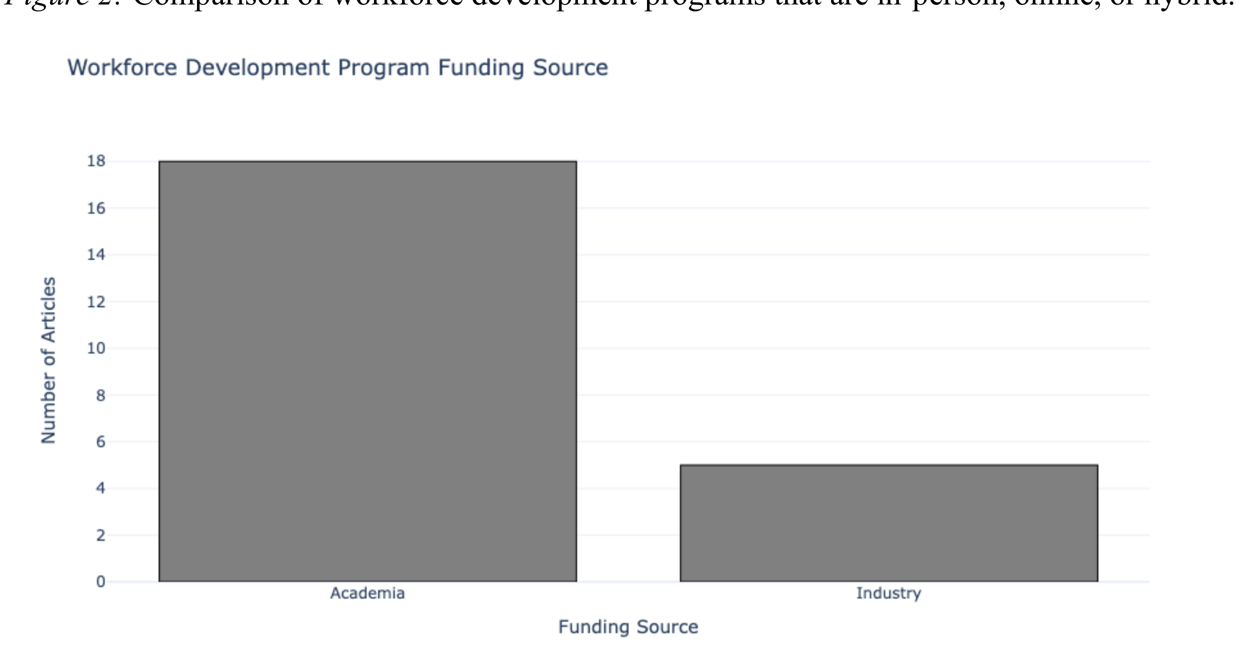

Figure 3: Comparison of funding sources for workforce development programs.

From Figure 3, it is possible to observe that workforce development programs were significantly more funded by academia (78%) versus by industry initiatives (22%). Academic funding primary came from the universities themselves or United States government agencies such as the National

Science Foundation (NSF) that are responsible for supporting and promoting science and engineering research and education across various disciplines. Industry initiatives were funded by companies such as Boeing, Microsoft Corporation, Linked In, and the United States Coast Guard. It is important to note that these results aim to compare the number of workforce development programs funded by academia versus industry; therefore, it is not a monetary comparison of the funding received by these workforce development programs.

In terms of targeted industries, there were 13 industries targeted during the development of workforce development programs (see Figure 4). The most targeted industries were STEM and Smart Manufacturing, along with civil engineering comprising 34% of the total targeted industries. STEM/Smart manufacturing and civil engineering industries both had four workforce development initiatives all funded by academia. Aerospace, cybersecurity, electrical engineering, and general engineering had two initiatives each. Computer science, education, mechanical engineering, military, ship building, solar energy, and technology industry had one initiative each.

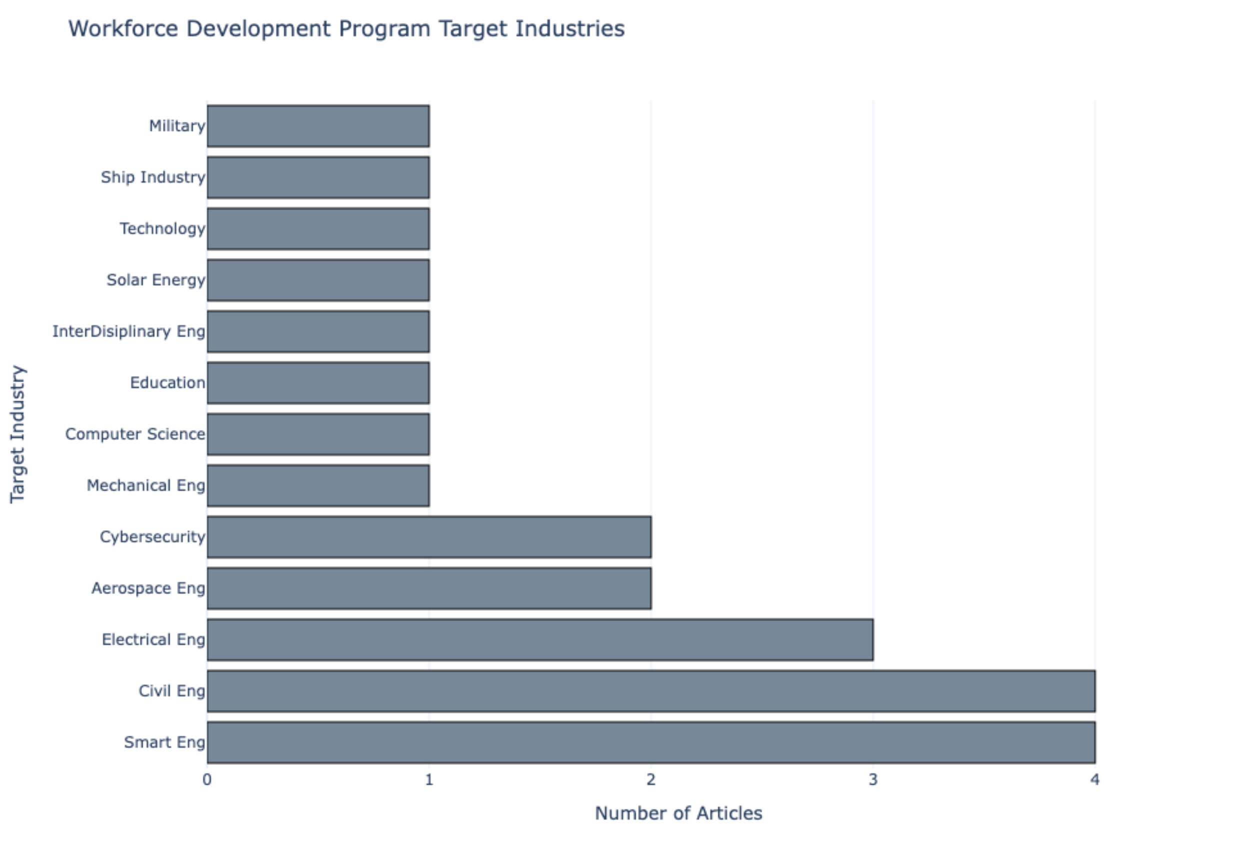

Figure 4: Targeted industries of workforce development programs.

As shown on Figure 5, 48% of the workforce development programs were created for industry professionals (n = 11), 26% were for students (n = 6), 13% were for students and industry professionals (n = 3), 9% were for academic faculty (n = 2), and 4% were for industry professionals, students, and academic faculty (n = 1). There was a wide range of topics for all the programs. In fact, each program was very niche and covered different objectives along with having different justifications for its implementation. The variety of topics covered by each industry workforce development program are shown in Appendix A.

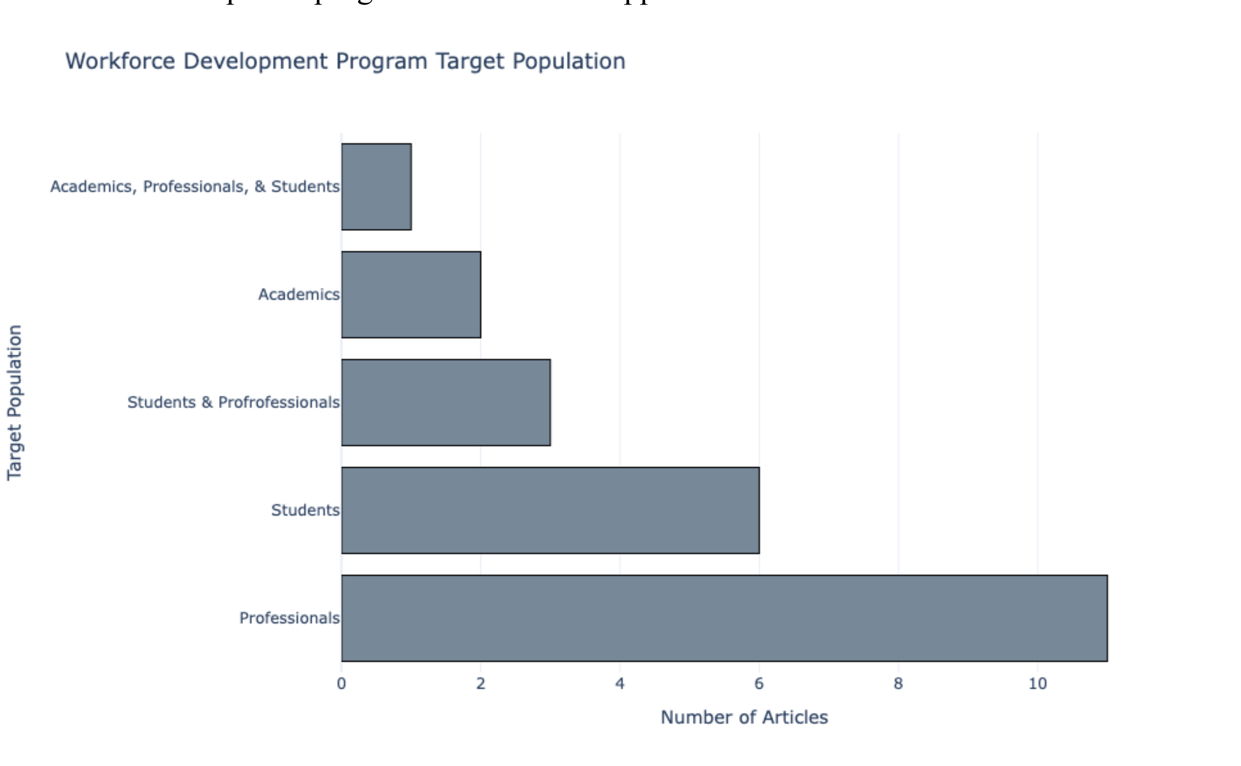

Figure 5: Targeted population of workforce development programs.

RQ2: What workforce readiness skills do these training programs have for engineering graduates?

Utilizing the Virginia Workplace Readiness skills framework and applying it graduate engineering programs in the United States, the workforce readiness skills programs are teaching students, academic faculty, and industry professionals (Table 2).

Table 2: Skills identified from the workplace development programs retrieved from literature and categorized using the commonwealth workforce readiness framework.

Workforce Readiness Skills	**Example Phrases Describing Skills According to Literature**	**Total Skill Count**
Personal Qualities and Abilities	• Confidence-building strategies o "In addition to improving their engineering and technology content knowledge, the teachers also received training on how to incorporate the engineering and technology content into the existing mathematics and science school curricula. The overarching goal was to encourage teachers to design and offer integrated STEM learning environments." [11]	Total Skills: 1
Interpersonal Skills	• Time management skills o "The key objectives were to increase knowledge and practical skills within the company's engineering organization, focusing specifically on time management as it relates to project and product delivery." [12]	Total Skills: 1

Professional Competencies	• Integration of MOOC modules and VR simulations
	  o "Our proposed hybrid learning methodology strives to enable faster procedural and synthesis learning that may facilitate just-in-time learning strategies that prevail upon communities of practitioners to help co-instruct in highly atomized modular training commensurate with both 2-year college advanced manufacturing tool infrastructure limitations and perennial upskilling strategy for incumbent industry workers." [13]
	• Training on cybersecurity threats
	  o "The workshop offered a case study on efforts to design and develop a social engineering awareness and training program that was implemented at the National Science Foundation Cybersecurity Summit using the National Institute of Standards and Technology framework for program development.
		Total Skills: 26

	This program was developed to enhance the ability for individuals in the future and current workforce to protect their organization against vulnerabilities to social engineering attacks through corresponding awareness and training" [14] • Research design and analysis o "Our team modified an existing assessment of students' exposure and motivation to focus explicitly on topics in microelectronics. The purpose of this paper is to evaluate validity evidence in terms of item functioning and factor structure. Specifically, we ask: 1) To what extent do the Exposure and Motivation items function as intended (i.e., items written to be exposure factor together and items written at motivation factor together); 2) To what extent are the items measuring Exposure and Motivation in microelectronics in a sensitive way (i.e., the items are able to detect the expected variance among students)?" [15] o "This workshop aims at bringing together academic researchers and industry practitioners to brainstorm and articulate a research agenda and identify key open questions in the RecWork domain. This workshop will be designed to kickstart a working group that will develop resources and datasets that will broaden the RecSys community" [16] • Data analysis for exploring fundamental concepts o "We have developed an educational toolkit that leverages an inexpensive bench scale extrusion platform to provide lab activities and feature-rich data to explore fundamental concepts of smart manufacturing in a production context for an audience of both undergraduate engineering students and current manufacturing workforce members. Through investigation of the mock production platform and associated data concepts and applications of modern data-driven tools are explored in the topic areas of data collection and the industrial internet of things, data analytics and predictive modeling for production data, simulation and digital twinning, and process and manufacturing systems optimization" [17] • Project and product delivery o "Phase (4) was having trained and untrained groups work together in a Joint Architecture Design (JAD) session. [...] The JAD differs from normal work activities where individual teams focus only on those subsets of the total solution that are within the team's areas of expertise. This approach often leads to	

	uncoordinated designs and fragility in mid- and long-term lifecycle of the resulting product. For strategically important initiatives such fragility risk is not acceptable and the solution is to employ a JAD process to coordinate the efforts of multiple teams. JAD projects are often stressful since the groups involved are not used to collaborating and JAD deliverables are highly visible to the organization, critical to strategy delivery and often on accelerated schedules."[12] • Introduction to engineering concepts o "The introductory DaDT syllabus covers the fundamentals of durability, fail-safety, and damage tolerance and how these principles are used at BCA" [18] • Methodology for capturing critical information o "Properly capturing and retaining employee's tacit knowledge is a labor-intensive task as it is usually transferred through personal observation, demonstration, mentors, apprenticeships, or on-the-job training. Consequently, articulating the tacit knowledge of an aging workforce is a challenging and time-consuming effort without proper preparation, oversight, and application of established knowledge retention strategies" [19] • Communication of MBSE aspects o "The contents of the Bootcamp were designed to provide a platform for audiences across the industry and academia with insight on the Why, What, Who, and How aspects of MBSE" [20] • Diversity and mission readiness planning o "Using the framework presented in this paper, more than 100 diverse students and faculty at the U.S. Coast Guard Academy - in a ground-breaking innovative first for the service - directly supported Coast Guard hurricane response operations" [21] • Workforce development framework o "This paper proposes a framework for systematically developing a diverse, mission-ready, and innovative Coast Guard workforce" [21] • Virtual teaching skills o "Methods for online labs and workforce training have been developed and deployed on a virtual basis. These labs and simulation environments have been deployed in signals and systems and DSP classes as well as in workforce development programs such as the REU and RET"[22]	

	• Lab adaptation for remote learning
	  ○ "To accomplish this, activities for Internet of Things (IoT) digital twin creation and digital twin use in the optimization of manufacturing process were developed to create a Factory 4.0 Toolkit. Materials from this toolkit were presented to undergraduate students and current workforce members in order to assess and organize an overall approach to Smart Manufacturing training" [17]
	• Knowledge transfer on cybersecurity threats
	  ○ "Overall, the paper and the proposed curriculum hold the promise of contributing to the ongoing effort to bridge the knowledge/skill gap by educating the future engineering and security workforce on protecting the ICS and CI from cybersecurity threats and attacks" [23]
	• Project management
	  ○ "A key feature to the Artemis ground operations at KSC is the deployment of Artemis and the Exploration Ground Systems (EGS) teams working together to ensure that assembly and integration handoffs are well defined and coordinated. This approach provides a seamless integration of spacecraft elements and integration to the SLS launch vehicle" [24]
	• Industry-relevant knowledge transfer
	  ○ "Our departmental Vision supports this proposal of giving the students robust technical knowledge through industry certificates and degree courses to be industry-ready and able to deliver results as soon as they join the workforce or as entrepreneurs" [25]
	• Workforce preparation strategies
	  ○ "Workforce development in civil engineering is a set of interconnected programs and policies designed to provide education and training for current and future engineers to thrive in an industry with growing challenges and evolving demands. Workforce development aims to support individual capacity and organizational prosperity while bolstering national competitiveness and innovation" [26]
	• Program evaluation
	  ○ "This project supported by a National Science Foundation (NSF) CAREER award employed a mixed methods approach to explore out-of-class engagement of engineering students including their decisions to participate (or not), types of activities, barriers and incentives. This research was designed to understand	

	how co-curricular participation supports involvement, affective engagement, and learning outcomes with the ultimate aim of leveraging workforce preparation and entry" [26] • Training program design ○ "VDSP has taken these results and is applying them to improve current and develop new curriculum to upscale the current workforce and prepare the future digital natives as they enter the workforce. As of January 1, 2020, four new courses and workshops have been integrated at the K-12, community college, and bachelor's level" [27] • Strategy development ○ "To overcome these challenges the construction industry should identify and implement effective strategies to develop a skilled workforce and then maintain and retain the developed workforce in a systematic manner. This systematic process increases workforce sustainability, a measure of the extent to which the workforce is sustainable" [28] • Educational program development ○ "The workshops will discuss the education systems and pathways for workforce development in mechatronics; pedagogies, tools, and assessment methods for learning; technological progress in mechatronics; and societal impacts such as workforce diversity" [29] • Integration of technology in teaching ○ "The workshops will also address the current technical development of teaching methods and tools for mechatronics, including extended reality (XR) — encompassing Virtual Reality (VR), Augmented Reality (AR), Substitutional Reality (SR), and Mixed Reality (MR) — which provides more freedom to cover both theoretical and practical learning with the assistance of other software" [29] • Student engagement strategies ○ "An integral part of the curriculum includes three classes that involve real world experiences and partner with local business to ensure relevance and cutting edge expertise: Introduction to Software Engineering partners with Elevator 3 to offer real-world projects and current technology trends. Students learn Database Schemas, API(s) development, and React. The Information Systems (IS) course partners with Envoc. The .Net Core Framework for Windows is	

	used for this class as well as many other technologies" [30] • Curriculum design for real-world skills o "An integral part of the curriculum includes three classes that involve real world experiences and partner with local business to ensure relevance and cutting edge expertise: Introduction to Software Engineering partners with Elevator 3 to offer real-world projects and current technology trends. Students learn Database Schemas, API(s) development, and React" [30] • Lab activity design o "We have developed an educational toolkit that leverages an inexpensive bench scale extrusion platform to provide lab activities and feature-rich data to explore fundamental concepts of smart manufacturing in a production context for an audience of both undergraduate engineering students and current manufacturing workforce members" [17] • Strategic planning for information retention o "It is crucial to have a balanced and working system for a functioning organization, but any implementation is preferable to none. This paper examined the methods and strategies utilized to capture and retain critical information within a local utility" [19] • Platform development and management o "Workshop participants were provided with resources and training on model-based systems engineering that will further contribute to developing a competitive workforce of underrepresented citizens across all the careers stages in the Rio Grande Valley region and beyond impacting the manufacturing, automotive, and production industry" [20]	

Discussion:

This study aimed to explore the workforce readiness skills being taught to graduate engineering students at workforce development programs. Our exploratory study aimed to investigate the various identifying characteristics of training programs and contribute to the existing body of knowledge of the emerging field of Engineering Education.

The key findings of the literature were the characteristics of the workforce development programs. The method of delivery of most training programs (n= 14) were in-person. This aligns with the importance of in-person instruction in the engineering field to enhance workforce readiness skills such as teamwork, communication, and time management. Additionally, our analysis revealed that majority (n=18) of the workforce development programs were funded by academia. These funding sources included but were not limited to the NSF (National Science Foundation), U.S department offices, and universities themselves. The five industry initiatives were funded by private sector companies including Boeing, NASA Kennedy Space Center, Microsoft and LinkedIn, the Commonwealth of Virginia, and U.S. Coast Guard. It is worth investigating to see if there is a need for industry to fund more workforce development programs so that it can be explored further in the future.

There was a wide range of targeted industries (n= 13) for the workforce development programs retrieved through this literature review. It is important to note that amongst the reviewed papers, not all engineering disciplines were addressed, perhaps due to the nature of the industry itself. This suggests there could be a potential gap in workforce readiness skills for engineering disciplines not offering graduate engineering students workforce development programs to help them advance their skillset. A limitation of comparing the funding sources is that little information is available regarding the monetary value of each funding source; therefore, we were unable to compare the average dollar amount per number of accepted grants and normalize them per sector. Furthermore, the target population for most of the workforce development programs were industry professionals. This factor is an interesting one as it can be interpreted multiple ways. The first being that engineering graduate students are not equipped with the proper workforce readiness skill upon transitioning to the workforce; therefore, workforce development programs must assist in filling in the skills gap after career onboarding. The second being that academia and industry initiatives need to increase their workforce development programs so that upon graduation students are properly equipped with the necessary workforce readiness skills for their respective industry. More in-depth analysis needs to be performed to assess the current workforce readiness skill level at which engineering graduate students enter the workforce along with employer satisfaction of the workforce readiness skills of onboarding engineers transitioning to their respective role.

Our study also explored the specific workforce readiness skills taught to participants at workforce development programs and then categorized them using the Virginia Workplace Readiness skills framework. Professional Competencies was the category with the most skills, whereas personal qualities and abilities and interpersonal skills only had one skill each. This suggests that professional competencies were targeted more in the workforce development programs evaluated in this study leaving personal qualities and abilities along with interpersonal skills development at a loss. Although professional competencies in engineering are important as they relate to technical knowledge and abilities, engineering also requires interpersonal and personal qualities as it is an interdisciplinary field. In a broader sense, engineers not only need to learn how to work and communicate with other engineers but also with personnel from other departments. This requires engineers to transfer their professional competency knowledge through verbal and written communication since the engineering design process involves more participants than those who are engineers.

Next Steps:
It was evident from this exploratory study that workforce development programs must assist in filling in the skills gap existing amongst Ph.D. graduate students in engineering and that this may need to happen they are onboarded at their respective workplaces. At the same time, it is less clear what are exactly the workplace readiness skills that these Ph.D. students in engineering skills have

and in what ways they can be transferred into industry and other workplace settings. As such, it will be important for institutions of higher education and in particular the Graduate School in these academic settings to begin to determine the personal, professional, and technical skills that are considered workforce ready and transferrable. Finally, transition pathways into the workforce may require additional trainings not identified in this work such as working mindsets and habits of mind that may further equip these Ph.D. students to handle transitioning working roles and work expectations. While not much is known in these areas, in practice, beginning to discover the skills as well as the professional identities that these Ph.D. students in engineering identify with is a place to start.

Conclusion:
In conclusion, this literature review on workforce development programs for engineering graduate students provides an initial look at target areas of workforce development programs by identifying what workforce development programs exist in the literature and what they are teaching. Through this systematized literature review, we have summarized and categorized the workforce readiness skills taught in each of the workforce development programs using the Virginia Workforce Readiness Skill framework. The main takeaways are: (1) the disparity of funding sources with academics funding most of these workforce development programs (2) Some programs offering more development programs such as construction management (3) Most programs being tailored to professional skills and leaving behind interpersonal and personal skills. Furthermore, our findings highlight the importance of continuing to investigate what workforce readiness skills are the most valuable for engineering graduate students to have when transitioning to the workforce, whether it be academia or industry. This approach will not only prepare engineering graduate students for the complexities and challenges of the engineering profession but also promote a culture of continuous learning and improvement. In summary, this research underscores the critical role of workforce development programs for engineering graduate students. By enhancing these approaches, we can better prepare the next generation of engineers to meet the challenges for the future, driving progress and innovation in an ever-changing world.

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Appendix A:

Industry	Programs	Topics
Aerospace	• Effective durability and damage tolerance training: new methods for modern learners [18] • Artemis Innovative Assembly and Integration Operations of the Launch Abort System at KSC [24]	• Durability and damage tolerance • Artemis assembly and operations for a launch abort system
Civil Engineering	• Concrete Bridge Engineering Institute (CBEI) [26] • Towards an Immersive Robotics Training for the Future of Architecture, Engineering, and Construction Workforce [31] • How to improve workforce development and sustainability in construction [28] • Defining workforce development in civil engineering: Launching a career from CAREER [26]	• Concrete bridge engineering • Immersive robotics training • Workforce development and sustainability
Computer Science	• Industry connect initiative: partnering for student success [30]	• Connecting students to workforce skills and opportunities

Cybersecurity	• Curriculum Development for Teaching Cybersecurity of Industrial Control Systems & Critical Infrastructure [14] • A social engineering awareness and training workshop for STEM students and practitioners [14]	• Curriculum development for teaching cybersecurity • Social engineering awareness
Education	• Improving In-Service Science and Mathematics Teachers' Engineering and Technology Content and Pedagogical Knowledge (Evaluation) [11]	• Improving in-service science and math teachers engineering knowledge
Electrical Engineering	• Workshop development for New frontier of mechatronics for mobility, energy, and production engineering [22] • Validity Evidence for Exposure and Motivation Scales in a Microelectronics Workforce Development Program [15] • Experiences with Web-based Signal Analysis Laboratories and Online Training during the COVID-19 Period [22]	• Mechatronics • Examining students' exposure and motivation in microelectronics careers • Web based signal analysis lab and online training during Covid-19
Interdisciplinary Engineering	• Adapting an NSF-Funded Professional Skills Curriculum to Train Engineers in Industry: A Case Study [12]	• Professional skills curriculum to train engineers in industry
Mechanical Engineering	• Study of Organizational Knowledge Retention Practices in the Utilities [19]	• Organizational knowledge retention practices
Military	• Beyond Buzzwords and Bystanders: A Framework for Systematically Developing a Diverse, Mission Ready, and Innovative Coast Guard Workforce [21]	• Framework for mission ready coast guard workforce
STEM/Smart Manufacturing	• Online Model-based Systems Engineering (MBSE) Bootcamp: A Report on Two Day Workforce Development Workshop [13] • Factory 4.0 Toolkit for Smart Manufacturing Training [17]	• Model-based systems engineering • Toolkit for smart manufacturing • Cyber and smart manufacturing education

	• Educating the workforce in cyber & smart manufacturing for industry 4.0 [32] • Leveraging MOOCs in a hybrid learning bootcamp model for training technicians and engineers in STEM manufacturing [13]	• MOOC hybrid bootcamp model for training technicians and engineers in STEM manufacturing
Shipbuilding and Ship Repair Industry	• Virginia digital shipbuilding program (VDSP) - Building an agile modern workforce to improve performance in the shipbuilding and ship repair industry [27]	• Digital ship building program to improve performance in the shipbuilding and ship repair industry
Solar Energy	• Solar Energy Certificate for Engineering Technology Students [25]	• Solar energy for engineering technology students
Technology	• RecWork: Workshop on Recommender Systems for the Future of Work [16]	• Recommender system