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Classroom to Workplace: Knowledge and Skills Learned by Recently Hired Aerospace Engineers

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A primary outcome of the organizational socialization process for new hires is learning how to complete tasks successfully, which requires learning new knowledge and skills. Although researchers have investigated the knowledge and skills essential for engineers in general, research specific to the aerospace industry has been overlooked. Herein, semistructured interviews were used to explore the perspectives of newly graduated aerospace engineers, each with less than three years of work experience, to gather insights into the new knowledge and skills they needed to learn to do their jobs. Ten interviews were analyzed with an open coding process, and the participant responses were classified into different categories of knowledge and skills. The qualitative method generated rich contextual data, allowing us to identify new types of knowledge and skills that are missing from the related literature dominated by quantitative studies. Our findings show that new workers must learn new knowledge and skills related to electronic hardware, software, and aerospace business operations. The study leads to a call to update the curricula of existing aerospace engineering educational programs to help facilitate an easy transition from school to work and enable newcomers, as professionals, to adapt to the ever-changing industry and make valuable contributions.

I. Introduction

ORGANIZATIONAL socialization is the process of learning the content, behaviors, and attitudes necessary for a new employee to assume a specific role in an organization [1–3]. For college graduates with no prior work experience, transitioning from school to work is a significant change [4], and research has shown that a successful socialization process can help new employees adjust to their workplace, leading to both short- and long-term improvements in employee job performance, employee job satisfaction, and retention [4,5]. Moreover, "task mastery," which refers to the attainment of the knowledge and skills required to perform a particular job [6], has been identified as one of the primary outcomes of the socialization process [6–8]. Hence, for any industry, it is important to identify what knowledge and skills new employees must learn after joining their workplace, as these will play a crucial role in their socialization process. The importance of such knowledge and skills is further emphasized in the particular case of the engineering industry as the literature suggests that the proximal (lower impact and short-term) socialization outcome of task mastery leads to the distal outcome (higher impact and long-term) of employee job satisfaction [9]. Moreover, the significant usage of technical knowledge and skills required by engineers to complete their day-to-day responsibilities adds further interest to this subject.

Although certain knowledge and skills can only be learned in the organizational context in which they occur, society largely looks to higher education programs to develop the foundational knowledge and skills necessary for graduates to function as professionals in the industry [10,11]. However, in the field of engineering, significant doubt has been cast over the effectiveness of undergraduate programs in meeting this goal [12,13]. The literature suggests that engineering programs that inadequately prepare students for the industry can lead to increased costs on behalf of employers who must provide additional training to graduates, as well as cause many graduates to abandon the field of engineering over concerns of being ill-prepared for the industry [14,15]. The knowledge and skills that are most important to be a successful engineer in the industry thus need investigation, and this has been the focus of several researchers over the last two decades [16–20]. However, only a small proportion of these researchers explicitly focus on newly employed engineers and obtain insights about organizational socialization. Moreover, most of the relevant literature concentrates on general engineering, with only some authors investigating specific engineering disciplines such as chemical [21], civil [17], or software engineering [22]. An important engineering industry that has been under-researched in this respect is the aerospace and defense (hereafter A&D) industry.

The U.S. A&D industry comprises 49% of the global total aerospace sector and contributed $374 billion to the U.S. Gross Domestic Product (GDP) in 2018, which accounted for 1.8% of the U.S. GDP [23]. The aerospace sector directly employs 509,000 scientific and technical workers, and more than 700,000 workers are employed in related fields, with scientists, engineers, and technicians holding 25% of the jobs in this sector [24]. The A&D industry is unique from other engineering industries because the majority portion of the customer base is formed by defense and space organizations and other government agencies [25]. Despite being "one of the largest and most powerful industries in the United States" [24], there has been little research conducted to understand the knowledge and skills required specifically by new engineering graduates to successfully attain task mastery in A&D organizations. The only major work focused on learning the necessary skills and knowledge from the industry is a two-decade-old paper ranking the importance of different knowledge descriptors, skills, and experiences, according to a survey of engineers and engineering managers working in different A&D-related organizations in the United States [18]. However, there has been significant technological advancement in the aerospace sector over the last two decades. A steady increase in automation of tasks across all aerospace engineering and the availability of modern-day computational power to solve

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complex engineering problems [26] have made aerospace engineers embrace some knowledge and skills typically associated with computer engineers, whereas an understanding of electronics has become necessary to familiarize themselves with avionic components [27]. Moreover, like most other technical industries, the aerospace sector has been going through the fourth industrial revolution, also known as Industry 4.0 [28]. This revolution is characterized by large, interconnected networks of smart technical systems, and enabled by rapid innovations in a multitude of new technologies in the field of information systems, including Internet of Things (IoT), cyber-physical systems (CPS), wireless communication, embedded systems, high-performance computing, and big data. Such technologies are creating a paradigm shift in how aircraft and spacecraft systems are conceived, designed, and controlled, along with changing several aspects of the aerospace industry, from how airborne vehicles communicate with each other and ground stations to how pilots are trained [29]. This evolution of the industry is evidenced by the creation of large-scale projects to modernize the aerospace industry, such as the Next Generation Air Transportation System (NextGen) and Single European Sky ATM Research (SESAR), as well as the proliferation of unmanned aerial vehicles (UAV), private rocket enterprises, and integrated air-defense systems (IAD). These developments have also created a corresponding shift in the required knowledge and skill toolkit of today's aerospace engineer with an ever-growing emphasis on information systems [30].

The aerospace engineer of the 21st century needs not only to learn the principles of classical aerospace engineering, which include subjects such as material science, fluid dynamics, propulsion, and traditional control systems, but also arm themselves with the grasp of the aforementioned emerging technologies [31]. However, it has been reported that undergraduate programs still largely focus on the physical design of aerospace systems, doing little to prepare students with required learning in topics like avionics and software design [32]. Hence, there is a need to inform academia to better prepare students for the needs of the modern industry. A first step in that direction could be the identification of the new knowledge and skills, not taught in entirety by undergraduate programs, that graduates must learn immediately after beginning work in an aerospace organization. Additionally, besides considering the opinions of seasoned engineers, it is important to investigate the experiences and opinions of newly graduated engineers themselves to better understand the knowledge and skills required for them to be successful at their first place of work, given their unique perspective in this position [14]. Hence, in this study, we turn to engineers who have recently graduated and taken up their first full-time position (within three years at the time of their interview) to answer the following research question:

RQ: After joining their first-full time position in the A&D industry, what new knowledge or skills did new engineers learn that were necessary to perform their jobs?

The analysis of this research question enables us to categorize the knowledge and skills required by newcomers to successfully transition into their workplace and make valuable contributions, thus fulfilling task mastery [6]. Based on our findings, we inform the existing literature on potential areas to further investigate and update curricula to better prepare undergraduate students to become valuable professionals in the A&D industry.

II. Literature Review

As our research question seeks to identify the new knowledge and skills required by newcomers in the A&D industry, we first need to settle on clear definitions of the terms "knowledge" and "skills" that are informed by the literature. Therefore, we begin this section by exploring existing research for definitions of knowledge and skills and identifying consistent differences between the use of the two terms in the context of engineering. Subsequently, we synthesize the definitions of the two terms for our study. Further, when exploring the definition of knowledge and skills, we come across the term "competencies," which we find is often used in the relevant literature. Hence, we explore its definition as well and see how "competencies" encompass the definitions of both "knowledge" and "skills" as defined in the literature. We also survey relevant literature on newcomer socialization. The literature review reinforces the need to perform research on organizational socialization in the A&D sector and further enables us to identify the gaps in the existing literature concerning our specific research question.

A. Knowledge and Skills

Knowledge has been defined in the literature as the learning of specific facts, principles, concepts, strategies, connections, procedures, and theories in a certain domain [33–39], including the cognitive processes required to process information [40]. Beyond learning, knowledge also involves remembering and/or reproducing information [36]. Knowledge can be articulated in linguistic form (e.g., a paper or a book) and can be transmitted with relative ease [41]. Further, it is possible to acquire knowledge through a single experience rather than repetitive practice. Once knowledge is acquired, it does not require fundamental refinement but can be built on, reorganized, or absorbed more effectively [36]. Knowledge can be measured by the depth of understanding [37], which can be evaluated through testing. In layman's terms, knowledge is characterized as "know-what" [41] regarding a certain topic.

Skill has been defined by researchers as the ability to apply knowledge reliably in practical settings [33,37,40]. Skills always involve motor, material, or cognitive operations on or with some prerequisite knowledge [42]. Operations *on* knowledge result in completely new knowledge or new representations of old knowledge [36], while operations *with* knowledge lead to demonstrable results in the form of effective solutions to both well- and ill-defined problems [36,42]. Skills are not easy to articulate and hence not easily transferred [41]. They are hardly ever learned in one go [36], and proficiency requires training, experience, and close observation and interaction with a master of the skill [38,41]. Skill is measured by the degree of reliability [37], which is often difficult to identify or test. In layman's terms, skill is characterized as "know-how" [41] to apply knowledge effectively.

For the current study, we use the following definitions of knowledge and skills learned by an organizational newcomer. "Knowledge," on the one hand, encompasses the understanding of facts, concepts, theories, and requirements in subject areas relevant to the job of a newcomer and necessary to perform their job. For example, the theory of operation of an aerospace component or the specifications related to the design of an aerospace component constitute knowledge. On the other hand, "skills" involve the ability to effectively operate on or with prerequisite knowledge to obtain a practical outcome required of the newcomer at their job. Hence, learning skills closely follows gaining some prerequisite knowledge, although the depth of knowledge required to acquire a particular skill may vary. Specific examples of a skill would be using a computer-aided design (CAD) software to design an aerospace component that operates desirably or communicating effectively with fellow professionals. It should be noted that while the existing literature is divided on categorizing procedures, tools, and techniques into either knowledge or skills (as the learning of such procedures, tools, and techniques by newcomers in an industrial setting is directly related to delivering practical results), they are considered as skills under our synthesized definition.

Further, with respect to our research question, we define "new knowledge" as newly learned knowledge by an employee at their current workplace, which in its entirety was not known to them before starting the full-time position. The same goes for a newly acquired skill; i.e., it is an effective operation on or with some prerequisite knowledge that a participant learned at their job. The prerequisite knowledge, however, could come from a learning experience that predates the start of their full-time position.

B. Competencies and Student Outcomes

Besides knowledge and skills, the term "competencies," or its synonym "competences" [43], is often used in the literature to denote "the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations such as professional work, civic engagement, and personal life" [20,43–46]. Competencies serve as a common ground to tie the outcomes of different educational programs to industry requirements and offer a common language of understanding among various educational and industrial authorities [47]. Consequently, the desired student outcomes of modern educational programs in engineering are often specified in terms of developed competencies in outgoing students [20], as evidenced by the different accreditation criteria for undergraduate programs like the Accreditation Board for Engineering Technology (ABET) in the United States, the European Network for Accreditation of Engineering Education (ENAEE) in Europe, and Engineers Australia (EA) in Australia [19].

As knowledge and skills generally form subsets of competencies, the corresponding literature on engineering competencies can supplement our understanding of knowledge and skills important for engineering professionals in the industry. Thus, we filter the literature on engineering competencies to investigate knowledge and skills and omit other subsets of competencies, such as attitudes and behaviors that lie beyond our current scope.

C. Knowledge and Skills Important for Engineering Professionals

The literature pertaining to the knowledge and skills important for engineers in the industry is packed with research spanning nations [13,18,19], engineering disciplines [18,22,48], and data gathered from engineers at different levels in their careers [14,16,18]. A recurrent theme in these works is the importance of "technical knowledge" and "technical skills," which help an individual accomplish specific tasks related to practical engineering, computer, science, mathematics, and statistics [14]. Several authors emphasize the importance of technical knowledge for practicing engineers, either in its entirety [16,19,21] or by focusing on specific subsets, such as knowledge about specific equipment and processes [14] and knowledge of engineering design specifications [49]. Consistent with our definition of skills, operations on or with technical knowledge constitute the family of technical skills. Notable subsets of this family of skills include the application of technical theory to solve engineering problems [14,19,20,49], modeling and analysis skills [14,49], data analysis [20], and software skills [14]. The prominence of technical knowledge and technical skills in the literature is expected as they are fundamental to engineering and play an important role in constituting a distinct identity of the engineering profession [50,51].

Further, globalization has fueled a growing significance of an engineer's "professional skills" in the 21st century [52]. These are a family of nontechnical skills related to various professions, including engineering [14]. Also referred to as "soft skills" [53], such skills enable an individual to be an effective professional in the workplace, communicate with a range of audiences [13,16,17,19], function effectively on diverse and multidisciplinary teams [16,17,20], and plan and organize resources to accomplish tasks promptly [17,19]. However, researchers have emphasized that professional skills for engineers are only helpful in the technical context in which they are used; hence, they cannot be taught or learned in a vacuum [21,46].

D. Variation Among Different Engineering Sectors

As the discipline of engineering encompasses a diverse range of fields, some variation is expected in the knowledge and skills considered important among them. Unsurprisingly, this variation manifests primarily as differences in the type of technical knowledge and skills required in various engineering fields. For example, researchers exploring mechanical engineering emphasize the need to understand the principles of mechanics, thermodynamics, and material science, and to develop critical thinking skills for engineering problem-solving [54,55]. The important technical skills required by industrial engineers, however, are related to production management, logistics, and supply chain management [56]. With rapid developments in the manufacturing sector, there also appears to be a growing need for vocational skills for industrial engineers, which require going beyond the understanding of theory and focusing on practical trade skills [57]. Alternatively, software engineers require core technical skills in operating systems, security, hardware, networking, and databases [58]. However, because software engineering is a relatively new engineering discipline, researchers have identified key differences that distinguish it from other engineering disciplines, such as theoretical foundations that are less mature, the lack of well-developed notations, and an interdisciplinary culture [59].

Despite the variation in the types of technical knowledge and skills required by different engineering fields, there seem to be more similarities regarding important professional skills. Communication, teamwork, and time management are considered important skills across engineering disciplines [48,56,58,60,61]. Additionally, organizational skills, the ability to learn fast, and the ability to work independently are reported as important skills for software engineers [60], whereas entrepreneurial skills and leadership skills are highly regarded for mechanical engineers [61]. The skill of innovation is also gaining traction in rapidly developing disciplines such as industrial engineering and software engineering [56,59].

In the A&D sector, to the best of our knowledge, there is only one major paper focusing on the essential competencies of engineers from the perspective of the industry [18]. It ranks the importance of different components of the ABET outcomes for aerospace engineers based on a survey of experienced aerospace engineers. The corresponding knowledge and skill items with maximum ranking points are "Engineering Courses with Applications" and "Ability to Structure, Solve, and Report on Solutions in the Engineering Specialty," which are consistent with the family of technical knowledge and skills found in papers related to other engineering disciplines. However, it is impossible to derive deep insights into the knowledge and skill items from the research of Lang et al. [18], as it does not provide detailed definitions of the listed items. In addition, the paper [18] is over two decades old. In the meantime, much has changed in the aerospace sector, fueled by rapid growth in automation, computation, and interaction technologies [62]. Specifically, advances in technologies such as embedded systems, wireless communication, IoT, artificial intelligence (AI), and computational processing and storage [63] have significantly impacted how modern-day aerospace systems are conceived and implemented [32]. These changes strengthen the need to conduct in-depth research into the knowledge and skills required by engineers in today's A&D industry, from the specific objective of understanding and improving newcomer socialization in aerospace organizations and the broader objective of improving aerospace engineering education.

E. Knowledge and Skills Relevant to Newcomer Socialization

Although there is a major body of literature that has investigated newcomers' opinions about aspects of organizational socialization, such as the behaviors and tactics that help them socialize into their organization [2,64,65], there is no significant research on the specific knowledge and skill areas that new employees deem important to transition from university to the industry. Further, the papers that explore knowledge and skills for engineering professionals mostly consider the opinions of experienced workers [13,14,16,18,19], undergraduate students [14,16,17], or general undergraduate alumni [20,21]. Unfortunately, there is a lack of representation of newcomers to the engineering industry among these opinions, which further prohibits us from looking at knowledge and skills from the lens of the organizational socialization of newcomers. Those who have recently completed or are currently going through the socialization process are likely to provide accurate accounts of their experience, which can help researchers derive richer insights into the socialization process in A&D organizations.

F. Summarizing the Gaps in Existing Literature

Although the literature provides an overview of the knowledge and skills required to be successful professionals in engineering, we identify three distinct under-researched areas that are pertinent to our research question: First, there is a lack of research specific to the A&D industry. Since the paper by Lang et al. [18], much has changed in the A&D industry with a shift toward more automation [26] and incorporation of digital technologies [62,66]. Moreover, there is an under-representation of the voices of industrial newcomers in existing research. The identified skillsets mostly come from the opinions of experienced industry professionals, undergraduate students, or general undergraduate alumni (not specifically new graduates). Hence, it is of interest to learn how the opinions of newcomers in the industry compare to these findings. Finally, there is a dearth of research on the knowledge and skills required to achieve the socialization outcome of task mastery, which could enable a smooth transition from the university to the industry.

Based on the above-mentioned gaps in the literature, we decided to study the opinions of new engineers at their first job after graduation (within three years from the start of their job at the time of interview) in the A&D industry to identify the new knowledge and skills they reportedly learned to successfully do their job, and thus move toward task mastery.

III. Method

The majority of the literature on important knowledge and skills for engineers employs quantitative methods to analyze data gathered from questionnaires. Although such research serves the valuable purpose of generalizing findings to a large population, quantitative methods cannot be used to explore contextual descriptions of data. Instead, qualitative methods provide a way to generate rich and contextual data through participant interviews [21], enabling the reader to make personal connections to the study [67]. Qualitative methods have been insightful in social science disciplines for quite some time and are often considered to be better poised for researching human lives and experiences [68].

Only two of the surveyed papers on important knowledge and skills for engineering professionals employ a qualitative analysis of data gathered through participant interviews [14,21]. As a specific example of the benefit of qualitative research, we can turn to the finding by Martin et al. [21] that professional skills cannot be taught in isolation from the technical context in which they are to be used, mentioned previously in this paper. This insight came from an in-depth analysis of semistructured interviews and would not be possible to arrive at through a quantitative study. Similarly, qualitative research can shed light on details related to knowledge and skills, such as the specificity of the important knowledge and skills (e.g., detailed description of the skills that comprise the family of technical skills) or the variation in engineers' opinions at different levels of their careers (e.g., if a newcomer and an experienced engineer mean the same thing by communication skills). Hence, a qualitative study could be useful to understand the specificity of important knowledge and skills in the A&D sector, allowing us to describe them in more detail than what was possible through the survey conducted by Lang et al. [18].

Our goal is to explore the different sets of knowledge and skills that newcomers in the A&D industry consider necessary to perform their jobs. Instead of aiming to generalize our findings to a large population, which is typical of most of the relevant literature, we intend to arrive at a more nuanced understanding of the findings and, as such, adopt a qualitative method of inquiry. Instead of broad data (large sample sizes) that are characteristic of quantitative studies, the use of qualitative methods requires gathering data that is deep (rich, contextual descriptions). This results in a shift from large-scale superficial questionnaires to in-depth interviews of a relatively smaller sample size [67].

A. Participants

A set of three criteria was employed to include participants in the current study. Firstly, they had to have an undergraduate degree in an engineering discipline (not necessarily aerospace engineering). Secondly, participants had to be employed by an organization in the A&D sector since graduation. Whether a particular organization belonged to the A&D sector was determined by the description of the organization's business on its website. Thirdly, participants were required to have less than three years of full-time work experience (excluding internships or co-ops) at the time of contact with us.

We ended up with a list of 26 participants spanning across seven different A&D organizations and including three Fortune 500 companies, which also happened to be major U.S. defense contractors. Each participant recruited for the study received a $99.99 stipend for participation.

B. Researchers

The research team was composed of two faculty members, three graduate students, and three undergraduate students. Both faculty members are experienced in qualitative research methods; one specialized in engineering education and the other in higher education. All of the graduate students involved in this research are trained in engineering education and qualitative research methods through coursework. They come from diverse academic backgrounds, working toward degrees in aerospace engineering, electrical engineering, and engineering education. The undergraduate researchers are all aerospace engineering students. One of the graduate student researchers had one-year full-time professional experience in the software and analytics industry, and one of the faculty members previously worked for an aerospace contracting company. A different graduate student and an undergraduate student additionally had prolonged internship experiences in one of the largest A&D organizations, with the graduate student currently working full-time.

C. Interview Protocol

Semistructured interviews were conducted with each participant as they have been shown in the literature to be a useful tool for gathering rich qualitative data [69]. To answer our research question, interviewers asked each participant, "After joining the company, have you learned any new skills or knowledge necessary to perform your job? If so, what skills and knowledge have you learned?" If the participant did not report learning any new skills or knowledge, interviewers asked whether they had to improve existing skills knowledge. Further, based on the response of individual participants, researchers asked specific follow-up questions to gather finer details.

D. Data Preparation

Each of the 26 interviews was audio-recorded and subsequently transcribed by an external professional transcription company. Each transcript was read by three members of our research team, after which we selected 10 transcripts for the current study. These 10 interview transcripts had the most detailed and descriptive information and offered a variety of positionalities. These 10 transcripts provided an abundance of ideas that could be obtained from the entire set of 26 transcripts, with the other 16 interviews not providing sufficient additional perspectives compared to the chosen 10 interviews. Finally, the 10 selected interviews came from a subgroup of participants that, with respect to the entire group of 26 participants, was diverse in terms of gender and racial representation, undergraduate major, months of experience at their current job, and prior internship experience. However, it must be noted that despite our efforts to incorporate racial diversity, we ultimately had a pool of 10 participants, 70% of whom identified as white.

The demographic details of the 10 chosen participants are provided in Table 1. Each participant is given a unique identifier with two letters and a number, in which the letters represent the participant's race/ethnicity and gender identity, respectively. For example, WM1 stands for "White Man 1," whereas AW1 denotes "Asian Woman 1."

The 10 selected transcripts were then used to develop a codebook by inductively coding participant responses to the interview questions using the open coding procedure [70–72]. To do so, we first established a coding scheme for the codebook: the generic ideas in participant responses to the interview questions would become initial codes, whereas finer details would be captured by creating subcodes. Each code was given a name, not exceeding five words in length, to capture the central theme of the code, along with a descriptive definition, example quotes, and line numbers of those quotes in the transcript, for our reference [73]. Next, three coders individually coded the first transcript. The team then had a meeting to discuss, at length, what codes each person created and why and developed the

Table 1 Demographic information of the participants

Participant ID	Race/ethnicity	Gender	Undergraduate major	Months since start of job	Job title
WM1	White	Man	Aerospace engineering	10	Mechanical engineer I
HW1	Hispanic, Latino, or Spanish origin	Woman	Mechanical engineering	27	Manufacturing engineer
WM2	White	Man	Aerospace engineering	9	Systems engineer associate
WW1	White	Woman	Aerospace engineering	17	Propulsion engineer
WM3	White	Man	Aerospace engineering	4	Supplier quality engineer
AW1	Asian	Woman	Industrial engineering	3	Senior project engineer, additive manufacturing-supply chain
WW2	White	Woman	Industrial engineering	4	Industrial engineer
HM1	Hispanic, Latino, or Spanish origin	Man	Mechanical engineering	10	Quality engineer
WM4	White	Man	Aerospace engineering	6	Propeller design engineer
WW3	White	Woman	Aerospace engineering	9	Mission systems engineer

first unanimously agreed-upon version of the codebook. The first version of the codebook was subsequently used as the basis for the three coders to individually code the second transcript. New codes were added by each coder based on new information. Once again, through a team meeting, the coders decided unanimously to keep or remove each instance of coding to update the codebook to its second version. This exercise also involved updating existing code names and refining existing code definitions. This process of individual coding followed by a group discussion to update the integrated codebook was carried out successively for each of the eight remaining transcripts, ultimately yielding the final version of the codebook. The final codebook was revised in detail by the team, and an extra field was included in the codebook to put in notes to help coders understand the differences between codes, when to use a particular code, and when not to use one. This was primarily done to remove discrepancies in the understanding of the codes among the three coders. All 10 transcripts were subsequently recoded using the final developed codebook, which is presented in Table 2.

The overall research design process used to the development of the codebook follows multiple quality strategies discussed by Walther et al. [74]. Regarding the gathering of data, we tried to accommodate the diverse experiences of participants and thus did a purposeful sampling of participants for this research (given the participant pool available). Additionally, we remained true to the participants' words and developed an inductive codebook grounded in data. Multiple reliability checks at different stages, completed by different researchers, further made the codebook dependable, and the subsequent data analysis was conducted with an in-depth understanding of the relevant literature.

It is worth emphasizing that the codes presented in Table 2 are grounded in the data from the interviews and the codebook does not make an explicit distinction between knowledge and skills. Finally, the developed codebook was used to discover answers related to our research question, and, as motivated by our understanding of the literature, classify the participant responses into well-defined categories of knowledge and skills.

E. Analyses

The research question was analyzed using the developed codebook. Consistent with the definitions of knowledge and skill synthesized in the previous section, all of the relevant quotes in the codebook were classified by one researcher as either knowledge or skill. There were 24 such quotes—examples of quotes for each code are provided in Table 2. A second researcher was tasked with independently completing the same classification for a randomly chosen set of 12 quotes. A 100% agreement was achieved between both researchers, demonstrating the robustness of the definitions. We ended up with 13 knowledge quotes and 11 skill quotes.

Next, the 13 knowledge quotes were analyzed in more detail. Similar types of knowledge were grouped together into categories. Grounded in data, each category was given a thoroughly descriptive definition. Moreover, to situate our findings in the literature, the category names were derived from the knowledge areas mentioned in existing research whenever possible. However, new category names needed to be created for knowledge areas that had not yet been identified in the literature. In such cases, the code names in the final codebook paved the way for the category names. The same process was then repeated for the 11 skill quotes. The developed categories, their definitions, relationships, and example quotes are provided in the next section.

IV. Results I: New Knowledge Learned by Newcomers

Our data show that all new knowledge the newcomers gained after starting their full-time position can be organized into two broad categories: technical knowledge and operations knowledge. Each broad category is further divided into subcategories, as illustrated in Fig. 1. The different categories are shown in red text on gold background, whereas specific examples are denoted using black text on a tan background. The number in the parentheses beside each category in Fig. 1 represents the number of participants who mentioned learning an item in that particular category.

A. Technical Knowledge

"Technical knowledge" refers to facts, concepts, theories, and requirements related to understanding engineering systems, including their design, operation, analysis, applications, and advances. Such knowledge is required to perform tasks involving physical or computational technology. Nine out of the 10 participants interviewed said that they needed to learn some sort of technical knowledge at their new workplace.

Based on the participants' responses, technical knowledge can be further categorized based on the domain of engineering in which the newcomers gained knowledge: 1) knowledge in aerospace and mechanical engineering and 2) knowledge in electrical and computer engineering.

1. Knowledge in Aerospace and Mechanical Engineering

This category concerns the technical knowledge required to design, manufacture, sustain, and/or test mechanical systems or subcomponents of such systems, with an emphasis on mechanical systems required for the development of aircraft and spacecraft. It is important to note that this area of technical knowledge focuses solely on the mechanical aspects of aerospace systems. We further found that knowledge learned by newcomers in the current category composed of two different levels.

a. Fundamental Knowledge. "Fundamental knowledge" denotes the foundational and advanced understanding of aerospace and mechanical engineering concepts that the newcomers were required to learn to perform tasks on their job. Participant responses included learning about engines, propellers, and other aerospace parts. Some of the responses were as follows:

HM1: *"I guess from a technical standpoint, also learning how these parts [aerospace components the participant was involved with] work. When you get to the real nitty-gritty stuff, it's pretty*

Table 2 Final version of the codebook for the interview question: "After joining the company, have you learned any new skills or knowledge necessary to perform your job? If so, what skills and knowledge have you learned?"

Initial code	Subcode	Definition	Notes	Example quote
Engineering components		The newcomer learned technical skills and knowledge related to engineering components he/she uses in his/her new position.	1) Don't include knowledge of abstract theory or concepts, such as aerodynamics in general. 2) Components include tools used to create aerospace products as well as the individual parts or subcomponents of the products produced by the workgroup.	
	Software	The newcomer learned how to use or create specific software and programs.		"I have learned quite a bit specifically about how such things like Linux and Unix function and how that actually, how their features and capabilities are actually implemented within our end product."
	Electronic hardware	The newcomer learned how to use specific hardware and physical items, such as circuits or electronic instruments.	1) Focuses on hardware dealing with electromagnetic concepts, not on components mainly dealing with mechanical or dynamic concepts, such as aerodynamics or structural mechanics.	"I've learned a lot of basic circuitry and instrumentation stuff that I didn't really know coming out of college, and stuff that I use on an everyday-to-day basis now."
	Aerospace components	The newcomer gained an understanding of physical aerospace machines/components.	1) Does not include components that are primarily electronic, such as antennas, circuits, or control systems.	"Yeah, just generic knowledge of engines themselves instead of the math behind them."
Technical procedures		The newcomer learned how to accomplish specific tasks and assignments through standardized formal processes used in the workgroup or generally in the industry.	1) Includes test procedures or component improvement methods. 2) Code this whenever the newcomer has to learn a specific set of steps to achieve a technical task. 3) Includes technical problem-solving.	"Another example is continuing to observe how . . . operation of liquid rocket engines, high-level test procedure."
System regulations and requirements		The newcomer learned regulations, standards, or requirements for his/her system or workgroup.	1) Includes requirements set by the newcomer's organization for its final product, such as a goal. 2) Includes requirements set by customers or government organizations.	"I guess one of the other things too was outside from the engineering stuff, it was a lot of the FAA stuff. I guess I was not aware of all the . . . I mean, I knew it regulated or whatever, but all those different, like Part 35 is when you look at propellers. Then there's Part 23 for civilian airplanes and stuff like that and dealing with all those regulations and being able to tailor your design for those requirements."
Professional skills		The newcomer learned skills related to being a professional in general.	1) Does not include technical problem-solving skills or skills related to operating a business or nontechnical procedures. 2) Technical problem-solving should be coded as "technical procedures" but skills related to operating a business or workgroup nontechnical procedures should be coded as "operations knowledge." 3) Professional skills include communication and networking, time and project management, or general problem-solving methods.	"And then I've definitely improved exponentially in my engineering report writing."
Operations knowledge		The newcomer gained knowledge pertaining to business procedures or operations in the workgroup or industry.	1) Includes knowledge of how the newcomer's organization goes about doing its business and how work groups are managed. 2) Example: Project management is a professional skill, but the knowledge of how the newcomer's organization manages its projects is "operations knowledge."	"Acronyms, how DOD contracting works, contracting in general, how the defense industry does work. How new products are thought of, implemented, designed, built in the kind of defense industry."

interesting stuff. . . . It's crazy how these parts work in tandem with each other in the overall aircraft. I think that's also a pretty valuable skill or valuable knowledge, learning from these guys and just working with them."

WM4: *"Then some of the safety features on propellers, you have springs and counterweights so that if something happens to your engine and your propeller stops spinning or if something happens to your engine and your propeller's still spinning, then it'll naturally go back to a straight into the wind position to minimize drag. Learning about how that safety feature works, if everything failed, how do you make something work, I guess understanding that principle. I mean that was all centrifugal force about two different axes, torques, moment, stuff like that."*

b. System-Level Knowledge. "System-level knowledge" alludes to learning how different aerospace and mechanical components within an engineering system come together and interact to operate as a whole. Knowledge of the individual components falls under the

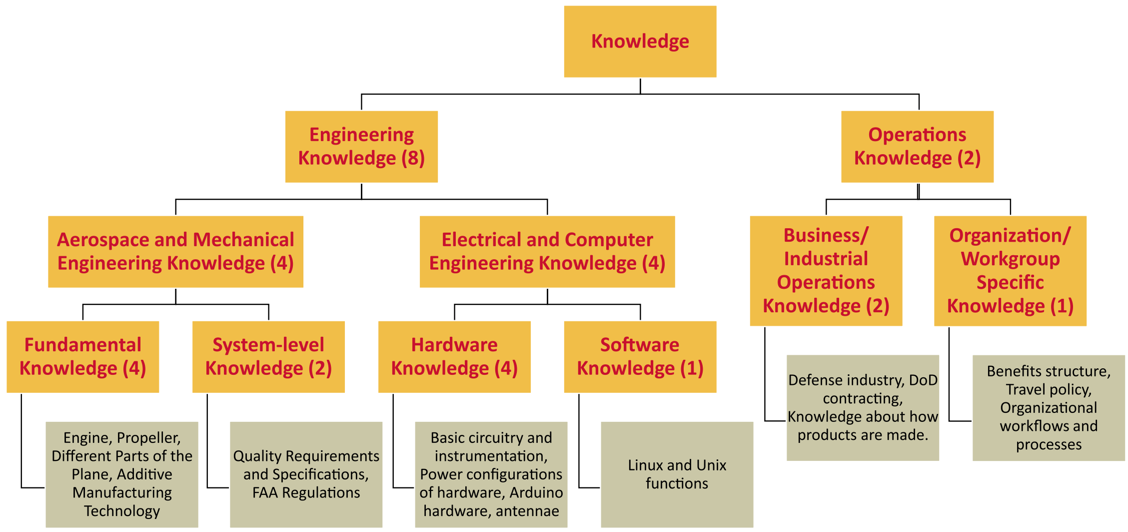

Fig. 1 Different types of knowledge, with examples, learned by newcomers after starting their full-time position.

previous class of foundational knowledge, whereas the current category emphasizes the interaction of the components to effectively work as a system. The knowledge of technical regulations, standards, and requirements, which different components of an engineering system and/or the entire system must adhere to, is key to understanding technical details at a system level. Hence, the knowledge of such regulations and specifications, set either by government organizations (e.g., the Federal Aviation Administration) or customers, is included in this category. A sample response that belongs to the category of system-level knowledge is given below.

WM4: *"I guess one of the other things too was outside from the engineering stuff, it was a lot of the FAA stuff. I guess I was not aware of all the . . . . I mean, I knew it regulated or whatever, but all those different, like Part 35 is when you look at propellers. Then there's Part 23 for civilian airplanes and stuff like that and dealing with all those regulations and being able to tailor your design for those requirements."*

2. *Knowledge in Electrical and Computer Engineering*

The other kind of engineering knowledge that newcomers had to learn concerned the discipline of electrical and computer engineering. This knowledge included two different features: understanding the functioning of physical electronic hardware and gaining knowledge about the functioning and capabilities of software systems. Hence, the responses in this category are divided into the following.

a. Hardware Knowledge. This category refers to learning the operation of specific electrical hardware systems. Responses included learning about basic circuits and instrumentation, open-source hardware such as Arduino microcontrollers, power configurations of specific hardware components, and the working of antennae. Sample responses are provided below.

WM1: *"I've learned a lot of basic circuitry and instrumentation stuff that I didn't really know coming out of college, and stuff that I use on an everyday-to-day basis now."*

WW3: *"And then a lot of the work I do deals with antennas. So I've been learning kind of the differences in various antennas and how they work and that kind of thing."*

b. Software Knowledge. One participant, who worked as a software engineer in an aerospace company, said that they had to learn functions of different operating systems and how the functions fit into their organization's end product:

WM2: *"I have learned quite a bit specifically about how such things like Linux and Unix function and how that actually, how their features and capabilities are actually implemented within our end product."*

B. Operations Knowledge

"Operations knowledge" forms the second broad category of knowledge learned by newcomers at their jobs. This refers to knowledge regarding how a particular industry, business, or organization functions, including different administrative procedures and standard business operations that a newcomer had to become familiar with to successfully do their job. Such knowledge is significantly different from technical knowledge, owing to its nontechnical nature. While technical knowledge focuses explicitly on the understanding of engineering systems, the current category involves the nonengineering knowledge required for managing the operations of a specific organizational workgroup, an organization, or the aerospace industry at large. Specifically, knowledge of regulations and standards that are technical in nature (e.g., quality requirements for aerospace components) is categorized under technical knowledge, whereas knowledge that is nontechnical and pertains to administrative operations of an organization or the industry (e.g., specifications for a certain business process) is placed in this category.

Based on the scope of the knowledge learned by the newcomer, we categorize operations knowledge as follows.

1. *Business/Industrial Operations Knowledge*

This category alludes to knowledge concerning the inner workings of a business or an industry, with a focus on the practices and procedures that sustain the business's operation. Such knowledge is administrative in nature, rather than technological, and thus involves having a larger understanding of the functioning of an engineering workgroup or organization in the context of the overall industry. It includes knowing customers and competitors, market trends, and being familiar with standard business practices. The responses relevant to this type of knowledge are given below:

WM3: *"Acronyms, how DOD contracting works, contracting in general, how the defense industry does work. How new products are thought of, implemented, designed, built in the kind of defense industry. There's been a lot more, as I try to think of these, it's been a lot more stuff I would not learn in school or stuff that school probably wouldn't teach me unless I took a military DOD work, or DOD business 101."*

AW1: *"I would also say different quality and inspection functions is what I've learned. So learning about how a part is made, what all goes into making an aerospace part."*

2. *Organization/Workgroup Specific Knowledge*

This category refers to knowledge about the inner workings of the particular organization or workgroup the newcomer worked for, including employee benefits, travel information, and other relevant organizational workflows. Such knowledge consists of details solely about the newcomer's organization or workgroup, thus differentiating it from business/industrial operations knowledge, which is aimed at an overview of the entire industry. Only one participant mentioned learning such knowledge and the response is provided below:

AW1: *"I would say a lot of learning that happened very initially, like in the first few months was not really a technical, like I said, it was more trying to figure out the benefits structure and if I were to travel, what are the different workflows and processes. It was not very technical."*

V. Results II: New Skills Learned by Newcomers

Concerning newly learned skills, the newcomers' responses are again categorized into two broad categories: technical skills and professional skills. They are further subcategorized, as shown in Fig. 2.

As with the knowledge categories, the different categories of skills are shown in red text on gold background, whereas specific examples are denoted using black text on a tan background. The number in the parentheses beside each category in Fig. 2 represents the number of participants who mentioned learning an item in that particular category.

A. Technical Skills

We define "technical skills" as effective operations on or with some prerequisite technical knowledge to achieve a practical goal, learned after the participants began their full-time position. Herein, "technical knowledge" has the same definition as presented under New Knowledge Learned by Newcomers. The operations under technical skills involve the ability to use physical or computational engineering tools or procedures so that learning a particular technical skill essentially becomes synonymous with gaining the ability to use such a tool or procedure successfully. Based on the kind of engineering tool or procedure a newcomer must learn to use effectively, technical skills are further divided into three subcategories: software skills, data engineering/analysis skills, and test procedures.

1. *Software Application Skills*

This class of technical skills involves the ability to use some software to achieve a desired goal. It is worth emphasizing that this set of technical skills concerns the application of software to obtain a desired outcome and not the skill of software development. Participants spoke about learning to code in new software (e.g., macros on Microsoft Excel), using CAD tools (e.g., CATIA), using data engineering tools to operate on data stored in servers (e.g., Structured Query Language), and using software to program and control hardware. The use of Arduino software to program Arduino hardware, for example, is a software application skill, whereas knowledge of how the Arduino hardware works, as mentioned previously, is regarded as hardware knowledge. Some sample responses regarding software application skills are presented below.

WW1: *"I have learned how to code in our company's own internal software. That's a language that I was not familiar with. I am now able to use CATIA, which I had never used. What else? I can now do macros in Excel, which is something that I never really learned either."*

WM3: *"Cue ground control, Tick Tock software. Arduino software and hardware?"*

2. *Data Engineering/Analysis Skills*

This set of technical skills concerns those skills typically related to being a "data scientist," that is, skills required to work with data. These skills particularly focus on the ability to collect, govern, prepare, transform, and analyze data. Such skills are closely associated with software application skills as one must use different types of software to perform different operations on or with data. Learning a software application skill means being proficient with using particular software; learning a data engineering/analysis skill, however, incurs being proficient with handling data, which might require the use of particular software. The focal point of such a skill is not on the use of the software, but rather the ability to operate with the data, which, for example, might call for the knowledge of database schemas or statistical techniques to find meaningful information in the given data. A newcomer response concerning this type of skill is reported below.

WW2: *"We spend a lot of time in spreadsheets, so I had to do a lot of learning about SQL servers, how to connect to information that we stored on different server, how to connect to information that we even have stored online. There is a lot of more technical knowledge that way that I needed to learn. I would say I have learned a lot more about data analytics and how to use some of the data that we have been collecting and how to make the data work for you and how to make it smarter."*

3. *Test Procedures*

This set of technical skills involves learning to effectively perform standardized test procedures on aerospace systems or their components. Such procedures might be standardized by the newcomer's workgroup or organization or might be an industrywide standard practice. A participant learning test procedures is construed as them learning the skill required to perform the procedure effectively in an industrial context, and not merely the knowledge of the procedure. Only one participant mentioned learning aerospace test procedures.

WM1: *"Another example is continuing to observe how … operation of liquid rocket engines, high-level test procedure."*

B. Professional Skills

We define "professional skills" as nontechnical skills that help improve the quality of a newcomer's work as well as his/her overall

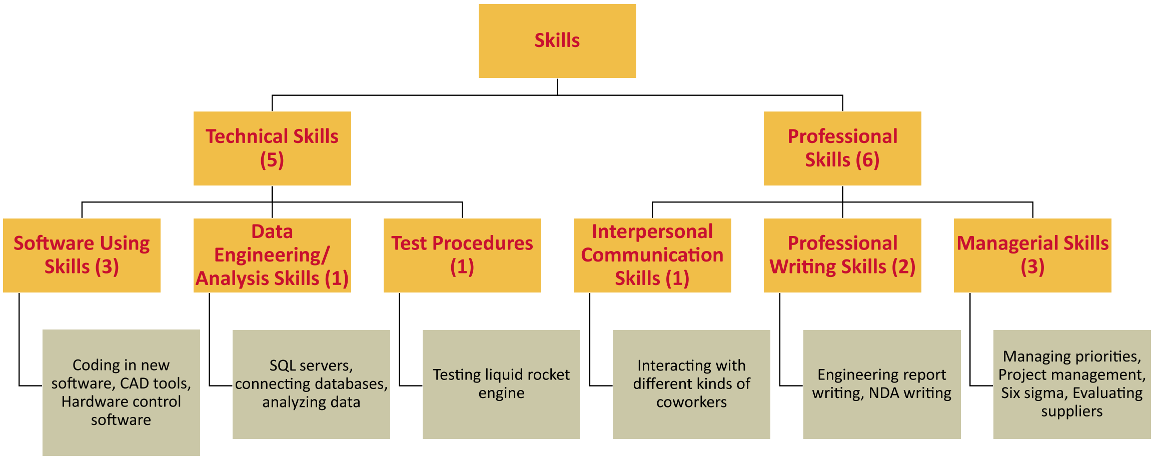

Fig. 2 Different types of skills, with examples, learned by newcomers after starting their full-time position.

development as a professional. These include "soft skills" related to communication and networking, writing and presentation skills, and management skills. We further categorize professional skills into three categories based on the participant responses.

1. Interpersonal Communication Skills

"Interpersonal communication skills" equip one to carry out effective verbal communication with other people in a professional context. Such skills focus on both the content of verbal communication along with how the communication takes place. One participant, who worked as a quality engineer, mentioned that he acquired the skill to effectively understand and talk to manufacturing and design engineers. His response is quoted below.

HM1: *"I feel just being able to talk to these guys and learning how to talk to these guys and understanding what I need to know about these parts has been a pretty valuable skill to learn, just because they will articulate the questions that you want to ask them. At the same time, you understand what information they're sharing with you, being able to operate with large teams that you might not know them personally, but you have same goal, so you have something to … like a foundation or basis to talk to them about."*

2. Professional Writing Skills

These are skills associated with writing professional documents such as technical reports, agreement letters, and contract documents. Two participants recounted developing professional writing skills after starting their full-time positions, with one learning how to write engineering reports and the other learning how to draft nondisclosure agreements (NDAs). Their responses are presented below.

WW1: *"And then I've definitely improved exponentially in my engineering report writing."*

AW1: *"Oh, one thing too, just going back on one thing that I've learned, I helped draft our nondisclosure agreements, so NDAs, that's another one of those business practices and supply chain functions that I've been doing."*

3. Management Skills

The final set of professional skills involves the ability to manage and administer work at a personal level or a project/group level. An example of personal management skills provided by our participants was learning how to manage personal work time and priorities, and examples of project/group management included learning project management and learning how to evaluate raw material suppliers for the workgroup. Sample responses are provided below.

WW2: *"Then, I had to learn a lot more about managing priorities. With school, you get used to you have a set schedule, things do not typically get, big projects do not get just dumped on you, saying, 'Hey, you have this really big project. It is due at 2 pm today.' That happens in the workplace. Managing the different priorities and learning how to sometimes tell someone that they are not going to get the information they want, but they will get it at a different time. That is not technical, but that was a skill to learn as well."*

AW1: *"And then I would say now with suppliers, learning more about how to evaluate suppliers and how to down select suppliers fairly and objectively and then still learning different business processes in general."*

VI. Discussion

The results of the current study identified the different knowledge and skills that newly employed engineers in the A&D industry were required to learn after joining their workplace in order to effectively do their jobs. The findings are relevant not only because they shed light on the socialization process in the aerospace industry but also because they inform how the landscape of important knowledge and skills in the aerospace industry has changed over the last two decades with the advent of increased automation and the availability of modern-day computational power.

When comparing the findings of the current work with existing research, we immediately notice that the identified broad category of operations knowledge has only been discussed by a few studies. Additionally, some authors have even claimed that what we call "business/industrial operations knowledge" (a subcategory of operations knowledge) is not important for new graduates who are just entering the engineering workforce [13,17,21]. This is despite the fact that globalization has led to today's engineers requiring substantial knowledge of the financial aspects and broader impacts of their engineering projects [52], thus needing expertise in business processes and management skills [51,75]. A logical assumption is that senior engineers, rather than those immediately out of college, are more involved in the operations of their organization's business. Nevertheless, our results suggest that new aerospace engineers needed to acquire nontechnical administrative knowledge related to the operations of their organization's business or the general operations of the A&D industry to perform the duties they were assigned. Based on the participant responses that helped us identify business/industrial operations knowledge, it appears that the relative importance of such knowledge could be specific to the A&D industry, given the large proportion of government and military involvement in this industry, which is not typical of other engineering industries. Furthermore, the current study has identified that some newcomers had to learn about the inner workings of their particular organization or workgroup—something that we did not find mentioned in literature. We categorized such knowledge as organization/workgroup-specific knowledge, and it forms the second subcategory of operations knowledge. Our use of qualitative inquiry has enabled us to reach this finer detail regarding operations knowledge, which has been missed by the existing research largely dominated by quantitative studies.

Although our definitions of the remaining three of the four broad categories identified in this work—technical knowledge, technical skills, and professional skills—align well with what has been reported by multiple authors in the existing literature, qualitative methods enable us to investigate these categories at a deeper level. While the data related to professional skills agree with existing research, we encounter certain types of technical knowledge and skills that have not been significantly investigated in the literature. We recognize an emphasis placed by new aerospace engineers on having to acquire knowledge in electrical and computer engineering (such as knowledge about electronic hardware and software), skills associated with using different kinds of software (such as CAD software and coding software), and skills to operate on and with data (such as using Structured Query Language servers and spreadsheets to gather and analyze data). Although such knowledge and skills have not been highlighted previously in the literature of important knowledge and skills for new aerospace engineers, their relevance aligns with the advent of the fourth industrial revolution as mentioned in the introductory section of this paper. The specific knowledge and skills related to electronic hardware and software, identified in this work, align with the need for today's aerospace engineers to be involved in computational thinking, design, and implementation of CPS and robotics [30,76].

A. Implications for New Engineers

The driving force behind this work was to identify the knowledge and skills that are important for new engineers in the A&D industry to achieve the socialization outcome of task mastery. Hence, the most direct implications of this study's findings are for those new engineers who are about to begin or are currently transitioning from the university to the industry. The identified sets of knowledge and skills can provide a guideline for newly employed engineers to self-assess their grasp of each important area and help them chart a course to improve their understanding of which knowledge and skill areas need further development. In workplaces without a formal onboarding process, newcomers can also use the findings of this study to proactively start conversations with their managers or other coworkers to enable them to provide the appropriate support required for the transition process. In these ways, the findings can potentially make the overwhelming process of transition to the workplace a more manageable affair.

B. Implications for Engineering Managers

The findings of the current study can help engineering managers enable a smooth transition from the university to the workplace for newly employed engineers, thus leading the newcomers to achieve task mastery more quickly. In particular, the knowledge and skills identified in this work can serve as a starting point for engineering managers and workgroup leads to develop training modules for newcomers. The organization of the important knowledge and skills presented in this work can be adopted to organize the onboarding resources for new employees at aerospace companies.

C. Implications for Education: General

As this study has identified knowledge and skills that newcomers in the A&D industry learn after joining the workforce, it is worth considering whether some of this knowledge and these skills can be taught to students at the university level. After all, as mentioned before, universities are expected to instill in their graduates the foundational knowledge and skills required to function as professionals in the industry. Although certain knowledge and skills, such as the category of workgroup/organization-specific knowledge, can only be learned after securing employment, most technical knowledge, technical skills, industry/business operations knowledge, and professional skills can be taught to university students. Educators at different universities can look for gaps in the knowledge and skills imparted by their aerospace engineering programs with respect to this study's findings and courses can be accordingly designed or modified to address those gaps. In particular, the knowledge and skills that would be of most interest to aerospace engineering educators are those that are not typically covered by traditional aerospace engineering courses. Hence, based on our findings, educators would be most likely to consider the following areas for creating new courses or modifying existing ones, or creating other learning opportunities for students.

1) *Electronic hardware and software (technical knowledge and skills):* As these topics align with what constitutes the current need for aerospace engineering undergraduate programs to keep up with a rapidly changing industry, they will be addressed in detail in a later section (see Implications for Education: Information Systems).

2) *Operations of the A&D industry (operations knowledge):* An exposure of undergraduate students to the "real-world" A&D industry can facilitate their learning of how the industry and its business practices function. Academic leaders at universities can work with industry organizations to provide such opportunities through internships, co-ops, and industry-sponsored school projects. Such collaborations would be beneficial for the industrial stakeholders as well as help create a more prepared incoming workforce. There are examples of university–industry collaborations being fruitful for students learning about business operations, as well as technical knowledge and skills, in the electric power industry [77] and the software industry [77,78].

3) *Professional skills including interpersonal communication, professional writing, and managerial skills:* To provide students with ample opportunities to hone such skills, aerospace engineering departments can collaborate with colleagues in other departments in their universities, such as communications, English, and management, who would have substantial experience in imparting professional skills in students.

Furthermore, the approach undertaken herein to distinguish between knowledge and skills, along with the provided definitions, can aid future education researchers to make similar distinctions both in aerospace engineering and other engineering disciplines.

D. Implications for Education: Information Systems

Several papers from educators have stressed the need to update undergraduate education in aerospace engineering to include aspects of information systems in order to produce qualified professionals for the rapidly changing modern-day aerospace engineering industry. Back in 2004, Long proposed adding "Computing, Information and Communication" as a new pillar alongside the traditional pillars of aerospace engineering [31]. Since then, educators have called for teaching aerospace engineering students knowledge and skills ranging from programming, embedded systems, and flight software systems [76] to electromagnetic compatibility, signals, and electronic hardware systems [79], as well as more crosscutting system-level skills related to CPS and robotics [32]. All these papers are authored by revered educators in aerospace engineering across the United States, where they share their decades of valuable experience in recommending an overhaul of the current aerospace curriculum. Our findings, which draw from the experiences of early career aerospace engineers, align with these expert opinions.

However, changing the aerospace engineering curriculum to better fit the needs of the modern industry is a large-scale task that cannot be achieved in a short span of time. In this paper, we identified sets of knowledge and skills related to electronic hardware and software that new engineers in the industry had to learn at the beginning of their jobs. Hence, these sets of knowledge and skills could provide a good starting point to slowly reform the current aerospace engineering programs. When asked a follow-up question on how undergraduate education could be improved, with regard to information systems, we recorded participant responses suggesting the inclusion of 3D modeling, kinematic modeling, programming in different languages, and embedded systems in the school curriculum. Participants also emphasized the need to have more practical problem-solving training, industry-driven projects, and more collaboration with other engineering departments. To provide such experiences to students and hone their knowledge and skills in electrical and computer engineering, educators can potentially incorporate project-based learning techniques, as has been demonstrated through the design-build-test effort for robotic manipulators [80] and small unmanned aircraft systems [81] at the University of Michigan, and the Research Aviation Training Device and Drone Testbed at Clausthal University of Technology, Denmark [82]. Additionally, to provide more exposure to information systems, aerospace engineering educators can collaborate with their counterparts in electrical engineering and computer engineering departments [76]. This could be manifested in the form of growing interdisciplinary minors and specialization programs like the CPS minor at Iowa State University [83]. Furthermore, the aerospace community can look at successful pedagogies emerging from electrical and computer engineering education research, on topics such as computer programming [84], embedded systems design [85], and CPS [86,87], and integrate and adapt the best practices for aerospace education.

E. Implications for Current Engineering Students

Finally, there are some strong implications of the findings for current aerospace engineering undergraduate students. Students can attempt to learn the important knowledge and skills required right after engineers are hired in the aerospace engineering industry on their own, even if the undergraduate curriculum does not teach some of them. It is a fair assumption that a strong understanding of the knowledge and skills important for newcomers in the industry would be desirable for recruiters and possessing such understanding might provide a student a competitive edge over others. Hence, a self-motivated student could take diverse courses across various departments in their university and participate in extracurricular activities that enable them to be better prepared for professional life and thus a stronger candidate for recruitment. Further, students could actively look for internships in companies or be part of teams for various government- or industry-sponsored national-level projects where they would get to innovate and build prototype aerospace systems. Such activities, in addition to honing students' technical knowledge and skills, will teach them about teamwork and the operations of a particular company. Moreover, such activities outside the realm of the traditional classroom would make students more competent learners, mindful of their own best learning habits and with an enhanced capability to learn independently [88,89], a skill that often remains underdeveloped inside the classroom as most of the learning comes directly from teachers. After the student graduates and begins working, these learning skills could be useful during the transition process to the industrial setting, where self-teaching is more common. This would allow him/her to socialize quickly in the new workplace and make valuable contributions as a successful employee.

Although we provide the above implications for current students, they are relevant only because of the shortcomings of the current academic system. A well-functioning academic system should not require students to do extra self-learning to make up for important knowledge and skills that their undergraduate program fails to impart. Hence, we return to the implications presented for education and call for stronger pressure on existing aerospace engineering departments to prepare current students for success after graduation.

VII. Limitations and Future Work

There are certain limitations associated with this study. Firstly, although we decided to select 10 interview transcripts of diverse gender and racial representation from a pool of 26 transcripts, the respondents to the interview request lacked racial diversity. In particular, we were unable to recruit any participant who identified as African American, Native American, or multiracial. Hence, the perspectives of those under-represented groups are missing from the findings of this study. By being more intentional about the recruitment of participants from under-represented groups, future research can include their voices and enhance the answer to the current research question.

Moreover, although our qualitative data enable us to formulate new categories of knowledge and skills important for new aerospace engineers, they lack the depth to investigate some of the categories in detail. Asking follow-up interview questions could lead to more specific details about some of the categories of knowledge and skills, and hence richer definitions. Such interview questions could be part of future work.

Furthermore, based on the findings of the current work, future studies could develop a quantitative survey to aid engineering managers in finding the knowledge and skill levels of new employees to help ease their transition into the workplace. In addition, future work could explore the differences in opinions among new engineers of different genders, races/ethnicities, and varying prior internship experiences. Moreover, it would be of interest to investigate the actions taken and challenges faced by the new engineers in their attempt to learn new knowledge and skills. Additionally, our findings can lead to a gap analysis between what is taught by aerospace engineering programs and what is required for new engineers to succeed in the A&D industry. Such an analysis could entail investigating existing curricula of aerospace engineering undergraduate programs and identifying similarities and dissimilarities between knowledge and skills imparted by them and those deemed important according to our findings. The insights gained could potentially lead to an updated curriculum that is better suited to the needs of the aerospace industry.

VIII. Conclusions

This study addressed the gap in existing literature regarding the knowledge and skills that newly graduated engineers at aerospace organizations must learn to successfully do their jobs, and hence attain the socialization outcome of task mastery. Herein, new employees were interviewed in major aerospace organizations in the United States, and the knowledge and skills that they deemed important to their work were categorized. Through our qualitative analysis, new classes of knowledge and skills were identified, along with richer details about certain knowledge and skills than what is currently present in the literature. Of particular interest is the importance of knowledge related to the business/industrial operations of the aerospace industry and the knowledge and skills typically associated with electrical and computer engineers that today's aerospace engineers must learn. The findings can guide new aerospace engineers toward the path of attaining task mastery, along with aiding current undergraduate students to prepare for industry positions. Moreover, they can inform engineering managers as well as engineering educators to develop more focused training materials and courses for new engineers and undergraduate students, respectively.

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