EXPLORATION OF THE TRAINING, EDUCATIONAL EXPERIENCES, AND TECHNICAL COMPETENCIES OF ENTRY-LEVEL MANUFACTURING ENGINEERS IN THE COMMERCIAL SPACE INDUSTRY

by

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I dedicate this to my family. My husband, Ed, and children, Six and Eleanor, who have believed in me, encouraged me, and have graced me with your patience through this process.

I could not have done this without you.

I love you.

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ABSTRACT

The commercial space industry is facing a shortage of qualified workers due to the aging and retirements of the workforce and the inability to find sufficient candidates who can meet the security requirements. Additionally, technically qualified individuals are also looking to other industries instead of space. The needs of the industry, and for manufacturing engineers specifically, are not well understood. In order to better understand and satisfy the needs of industry and for manufacturing engineers, the purpose and objective of this study was to explore the training, educational experiences, and technical competencies of entry-level manufacturing engineers. All the participants in the study had worked as a manufacturing engineer in the commercial space industry. There were five expert level and three entry-level manufacturing engineers (n = 8). Expert-level manufacturing engineers had at least three years of experience and entry-level manufacturing engineers had less than three years of experience. This qualitative descriptive study involved interviewing the participants to explore their experiences. Six themes emerged from the findings and included: (a) mentoring used as a teaching tool, (b) you're going to be doing pretty good, (c) worst case is millions of lives, (d) understand, be familiar, or proficient, (e) the interpreter or the bridge between the design engineer and the shop floor, and (f) the storyteller or make your data tell a story.

CHAPTER 1. INTRODUCTION

"More than by any other imaginative concept, the mind of man is aroused by the thought of exploring the mysteries of outer space. Through such exploration, man hopes to broaden his horizons, add to his knowledge, improve his way of living on earth."

— U.S. Department of State, *National Security Council Report*, August 18, 1958

Nature of the Problem

In 1984, there was a fundamental shift in the space industry in the United States. Previously, the space industry was primarily the purview of the National Aeronautics and Space Administration (NASA). While private corporations could participate, they did so at the behest of NASA; NASA was the final authority. NASA would determine requirements, and their engineers and specialists oversaw every aspect of development. Once the requirements were established, a private contractor was hired to build the system. NASA personnel were heavily involved in the testing and operation of the system, and the system was wholly owned by them (NASA, 2014). Companies in the private industry were only allowed to compete for predetermined and predominately already designed systems.

This dynamic changed when the Commercial Space Launch Act of 1984 was signed into law on October 30, 1984, by President Ronald Reagan (Commercial Space Launch Act, 1984). In his speech at the signing of the law, President Reagan discussed how this law would change the status quo by allowing private companies greater responsibility and assume increased risk in the unmanned expendable launch vehicle (ELV) industry (Christ, 2014). The objective was to "encourage the private sector in commercial space endeavors" (Reagan, 1984, p. 1). Increased commercial development, it was hoped, would result in increased efficiency and reduction in costs. The passage of the act changed the way the space industry operated. Instead of the hierarchical structure established in the early days of space operations, currently, the process is significantly more collaborative. Previously, NASA issued requirements and fully realized designs, and then early space-focused private companies would build it. The current work environment is much different. Rather than delegating designs, NASA works with private partners to develop the requirements before the project begins. Once the requirements are developed, the partners are free to design the system that they, not NASA, deems the "best".

Companies are in business to provide products and services while making a profit. To accomplish these goals, the expectation is that the companies design a system that maintains efficient and effective manufacturing processes. As a reward, the companies own and operate their systems with NASA as a partner, not just a purchaser of systems, but with insight into the design and manufacturing process (NASA, 2014). The transition from NASA as the director to partner affected significant changes in the space industry.

After establishment in the early 1980s, the modern commercial space launch services industry emerged and evolved at a quick pace in the United States. However, in recent years, the global commercial launch market has experienced minimal growth. Estimates for the growth of the global space economy vary between 3% and 8% in 2018 (Foust, 2020). Regardless of the minimal growth, the United States has increased its share of the market. In 2011, the U.S. had 0% of the market; by 2017 its share had increased to 54% (FAA AST, 2018). The global space economy was estimated to be between $360 billion to $415 billion (Foust, 2020). Although, some argue that the estimates were optimistic and the actual size of the market was about half (Foust, 2020). In 2017, private investors contributed $3.9 billion to the commercial space industry (Sheetz, 2018). Between 2005 and 2015, the amount grew to approximately $10B (Buckley, 2015).

There is an expectation that the global space market will continue to grow. One reason for the optimism is the largely untapped market for small payload launches (FAA AST, 2018). Currently, small payloads are dependent on the schedule set by the launches of larger payloads. An increase in the frequency of launches would provide the operators with greater control of their business plans. While the cost would probably not be less, the greater control and flexibility would be worth the additional cost (FAA AST, 2018).

The commercial space industry is exciting, but it does have challenges. One challenge to all companies, not just commercial space companies, is they are no longer able to operate as small and lean as they once did. Other challenges include outgrowing their physical space, the need to follow more regulations, or hire employees in additional functions or positions. However, the space industry has challenges that many other industries may not have. There are many challenges due to the dependence on United States Government (USG) contracts such as the age and skill of the workforce, the need to hire foreign workers to meet demand, and the inability to fill the open positions. A consequence of a rapidly changing environment, including the lack of workers skilled in the new and unique set of needs of the commercial space industry, is an urgent need to recruit a new workforce (Doule & Peeters, 2009; Malsberry, 2014).

While the commercial space industry is expanding its base to include commercial contracts, much of the industry is still dependent on contracts from the USG. In addition to the substantial technical requirements, working with the U.S. government requires any workforce that must also include the ability to meet national security and civilian needs (U.S. Department of Commerce, 2014). The USG influence on the industry is both positive and negative. The

USG provides a source of contracts, but when the contracts are canceled problems are created. When the USG canceled the Constellation program in 2009 and the Space Shuttle program in 2011, concerns were raised about long-term retention of the existing skilled workforce. In fact, for companies that were primarily dependent on USG contracts, the cancellation of those programs reduced the number of engineers, scientists, and research and development full-time employees retained in the workforce (see Figure 1) (U.S. Department of Commerce, 2014).

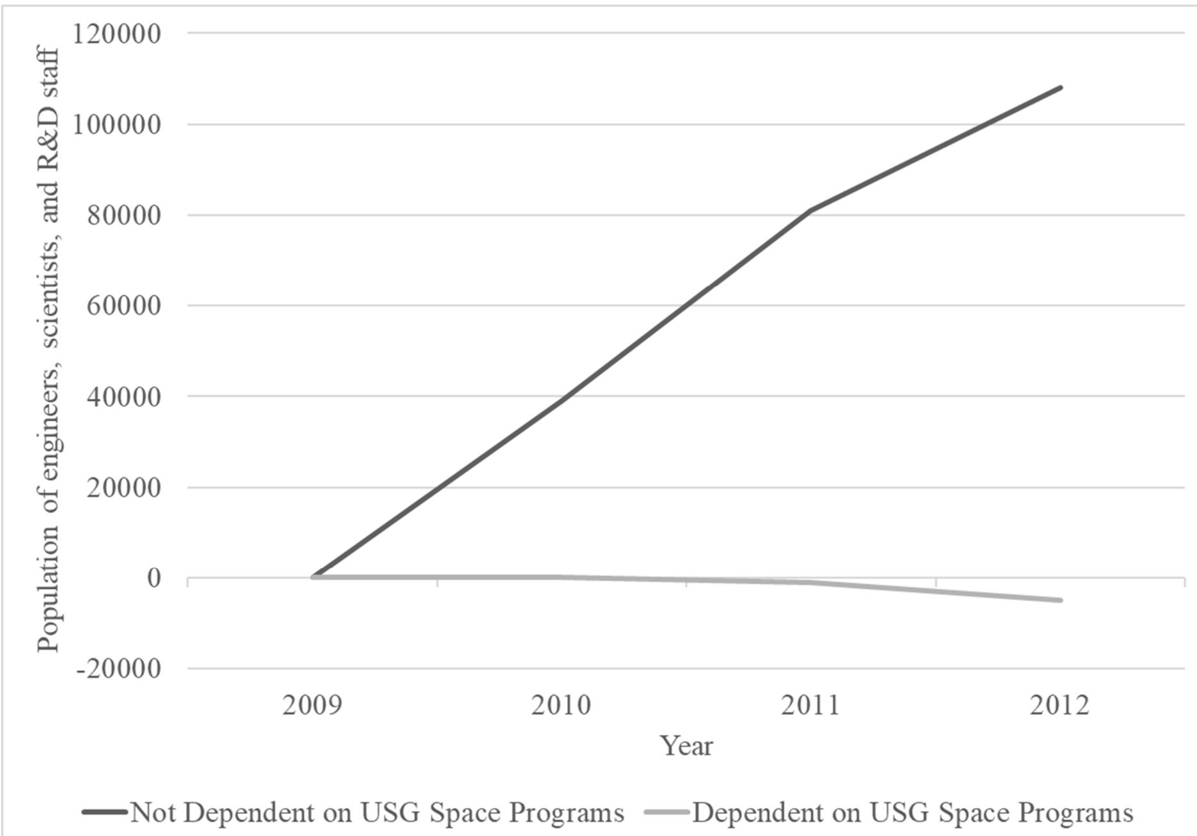

Figure 1. The net change in engineers, scientists, and R&D (U.S. Department of Commerce, 2014)

Some of the former employees were able to find positions at other companies, but many retired. Still, the workforce pool is becoming older and retiring, and it is challenging to attract younger talent. The requirements are high, and there are not sufficient young people entering the field to meet the need (U.S. Department of Commerce, 2014). As of 2014, the workforce of engineers, scientists, and Research and Development (R&D) personnel over the age of 50 was 43% (U.S. Department of Commerce, 2014). The aging workforce foretells a significant loss of talent in an industry that needs to maintain the technical excellence of the past. The difficulty is even greater when the future needs of engineers and scientists are included. Research from Giffi et al. (2015), indicated executives from manufacturing companies in the U.S. reported a shortage of 33% for engineers in 2014. By 2020, that shortfall increased to 48%.

In 2014, a study by the U.S. Department of Commerce found over 24,000 skilled positions unfilled (U.S. Department of Commerce, 2014). Companies that generated more than $250 million in sales accounted for 67% of those openings (U.S. Department of Commerce, 2014). Per a report from the Aerospace Industries Association (2016), 39% of aerospace companies perceived that the labor shortage was due to the lack of adequately educated candidates and was an “extreme” impact to their business (p. 2). This result was mirrored by a report from Deloitte and the Manufacturing Institute (Giffi et al., 2015). Eighty-one percent of their respondents said they were “facing a moderate to severe shortage of qualified workers” (p. 4). The inability to fill openings was credited to multiple reasons including the lack of proper skills and qualifications, geographic difficulties, the variability of demand, difficulty in attracting workers to manufacturing, and additional issues (U.S. Department of Commerce, 2014).

The commercial space industry requires unique skills and competencies (U.S. Department of Commerce, 2014). Identification of employees with the skills and education to be successful is difficult, partially due to limited information on what exactly those skills include. Research related to the required knowledge, skills, and competencies is minimal and general to the commercial space industry as a whole. Dubikovsky et al. (2017) and Mehta (2013) surveyed current commercial space industry professionals. The topics that emerged are similar between the two studies and include areas such as manufacturing, safety, terminology, and propulsion.

According to a U.S Department of Commerce study (2014), the two most common skills and competencies identified were: (a) engineering skills, and (b) production and manufacturing. Unfortunately, these topics are generic and are not focused on any specific industry or function. These topics can apply to a broad range of job functions and industry sectors. For example, the knowledge, skills, and abilities required for a manufacturing engineer are different from the knowledge, skills, and abilities required for a program manager. Although both may need to understand something about propulsion, the focus and detail required of each of them are different. The study also found additional skills were needed including analytical, scientific, management or development, quality control or testing, and design.

In addition to the technical knowledge required, there are also other factors that affect the workforce such as national security. While there are challenges to having the USG as the primary source of contracts, the USG is the largest buyer of commercial space products in the United States. It is critical that the commercial space industry recruits candidates who are technically knowledgeable and in possession of the appropriate clearances to work with government contracts. To meet the industry's workforce needs, companies are increasingly recruiting from foreign countries to find skilled and knowledgeable workers (U.S. Department of Commerce, 2014). This does raise concerns with citizenship and clearances of the workforce due to the demand from USG and other commercial contracts.

A general shortage of applicants for all positions was clear, but there is a greater need in some areas over others. Attracting workers to manufacturing positions was difficult (U.S. Department of Commerce, 2014). On July 22, 2018, a review of job openings at SpaceX, Blue

Origin, and United Launch Alliance (ULA), found that the majority of open positions was in the design and manufacturing areas. For example, of the 270 positions at SpaceX, 37% were in manufacturing including manufacturing engineering, test engineering, and production support. Of the positions at ULA, 34% were related to design engineering and included electrical engineer, propulsion design, and thermodynamics engineer.

Statement of the Problem

The commercial space industry faces challenges in training, hiring, and retaining valuable employees. The existing research, however, is limited with regard to competencies in the commercial space sector. The focus of existing research is on commercial space as a whole, not specific positions, even though there was no real expectation that a human resource manager would have the same required competencies as a mechanical engineer. This has created a gap in the research focused on a singular job position or function. Additionally, because the studies have not enforced any resource limits, there has been no need to place importance on competencies; therefore, all skills and competencies have been found to be equally needed. The examination of the required skills that are expected by industry professionals in the job function is one way to examine this issue. Accordingly, the major problem addressed by this study was that we do not understand the required training, educational experiences, and technical competencies of entry-level manufacturing engineers in the commercial space industry.

Purpose and Objectives of the Study

The purpose of this study was to explore the training, educational experiences, and technical competencies of entry-level manufacturing engineers in the commercial space industry. What should they know? Where and how did they learn it? What experiences in their education were helpful? How much depth in those competencies was required? How critical was it for them to know? Is the skill or competency critical because it was frequently used, or was it critical because a misunderstanding implies a loss of valuable equipment or even more critically, the loss of life? The objective of this study, therefore, was to explore the training, educational experiences, and technical competencies of entry-level manufacturing engineers in the commercial space industry.

Research Questions

The research questions posited for this study included:

1. What are the training and education experiences of entry-level manufacturing engineers?
2. What are the technical competencies required for entry-level employment as a manufacturing engineer in a commercial space manufacturing company as described by entry-level and expert-level manufacturing engineers?
3. How do entry-level and expert-level manufacturing engineers describe the importance of these competencies?
4. What level of knowledge of the technical competencies should the employee possess as described by expert-level manufacturing engineers?

Significance of the Study

A competent workforce is vital for a productive workforce (Khan et al., 2014/2015). However, the answer is not to increase required competencies without regard to the specific position, as there are penalties for being both under- or over-qualified (Büchel, 2002). There is a connection between competence, satisfaction, commitment to the job, and increased performance

(Hammed & Waheed, 2011). Competence is a signifier for the satisfaction of an individual for a particular position (Khan et al., 2014/2015). The more suitable an individual is for a position, the greater the chance the individual will be proficient and satisfied in their position (Hameed & Waheed, 2011). As an example, a person may have the skill to sort blocks into colors, but ability or competence alone is not sufficient to achieve satisfaction, commitment, and increased performance. Are they suitable for the task? Do they enjoy sorting blocks into colors? Do repetitive actions bring satisfaction or frustration? If it is frustration, they might be more likely to commit errors.

There is the question of when should an employee have those competencies? Should they have all of them on the first day they start working? Asking someone to start with all the competencies that will ever be needed for any position is unreasonable. Differentiating between those skills needed immediately versus the skills needed in the future influences the performance of the employee (García-Aracil & Van der Velden, 2008).

When employers search for the best fit for a new position, they have an expectation that applicants have a grasp of the fundamentals of their chosen disciplines. There is a belief that educational programs, especially those with a specific focus on their discipline, build the essential competencies into the curriculum. Unfortunately, although this is the desired result, there is still a separation between student outcomes and the needs of the workforce (AIA, 2016). Identifying the key competencies that lead to proficiency and competence is one step in closing the gap between curriculum outcomes and industry needs.

Delimitations of the Study

The major delimitation of this study was that the focus was only on manufacturing engineering in the commercial space industry. Additionally, a random sample of participants was not attempted for the interviews because of the inability to fully identify the population and identify a strategy to contact random participants. Further, this study did not focus on those non-technical employability skills needed in the workplace such as communication, teamwork, or leadership skills.

Assumptions of the Study

The first assumption was that participants would be identified and volunteer to participate in the study. The participants for the interviews were current employees in the commercial space industry. At some stage in their employment history, they were employed as manufacturing engineers in commercial space. Finally, the participants were assumed to provide timely, valid, and reliable data.

Definition of Terms

Ability: The potential to perform mental or physical activities, often associated with specialized professions (Wuim-Pam, 2014).

Additive Manufacturing: The process that builds 3D objects by adding layer upon layer. The material can include plastic, metal, or concrete materials (Additive Manufacturing, 2020).

Aerospace: Referring to both the earth's atmosphere, space, and the integration of both (Chun, 2001; NASA, n.d.).

Attitudes: Thoughts, feelings, and motivation about the job (Khan et al., 2014/2015).

Commercial Space: Space goods, services, or activities provided by private sector enterprises that bear a reasonable portion of the investment risk and responsibility for the activity, operate in accordance with typical market-based incentives for controlling cost and optimizing return on investment, and have the legal capacity to offer these goods or services to existing or potential non-governmental customers. (Obama, 2010, p. 10).

Competency: Knowledge, skills, and abilities that affect a major part of one's job, role, or responsibility; they correlate with performance on the job and are measurable against well-established standards, and can be improved through the use of training and development (Department of Labor Employment and Training Administration, 2010).

*Depth: "*The degree to which an individual is knowledgeable about a specific domain" (Mannucci & Yong, 2018, p. 3).

Knowledge: The understanding of facts, truths, and principles that results from job-related expertise, experience, and other factors (Khan et al., 2014/2015; Wuim-Pam, 2014).

Manufacturing Engineer: Personnel responsible for the "planning, tooling, coordination, and control of the manufacturing processes" that are "critical to the operation of an effective and efficient manufacturing system" (Elshennawy & Weheba, 2015, p. 9).

NewSpace: An ideology by commercial space companies that focuses on an explicitly free-market approach with a reduction in government fiscal pressures and regulations (Foust, 2007; Handberg, 2014).

Skill: An ability, either mental or physical, that is derived from practice or specialized training to achieve a level of expertise (Khan et al., 2014/2015; Wuim-Pam, 2014).

Space: Anything outside the boundaries of the earth's atmosphere (NASA, n.d.).

CHAPTER 2. REVIEW OF THE LITERATURE

This review of the literature begins with an examination of the challenges confronting the commercial space industry with regard to the workforce. These challenges include the loss of employees, the high cost of hiring the wrong employee, a stressful working environment, and the aging of the workforce. The aging of the workforce and the difficulty in replacing the workforce is causing a drain of experienced and technically skilled employees and their knowledge. Identifying and understanding the competency needs of the industry are difficult. Organizations and educational institutions have made some progress in identifying the competencies in the commercial space and manufacturing industries, in general. Their work is vital in beginning to understand the needs of the industry. The review of the literature concludes with a discussion of qualitative descriptive studies and strategies.

Personnel Challenges in the Commercial Space Industry

Eighty-four percent of executives in the manufacturing industry believe there is a talent shortage in the U.S. manufacturing sector (Giffi et al., 2015). The shortage is not shrinking, and the skills gap is expanding. Research estimates there will be 60% unfulfilled positions over the next decade, or approximately 2 million jobs (Giffi et al., 2015). In 2011, there were 600,000 jobs left unfilled (Giffi et al., 2015). The inability to identify and hire technically competent employees is a limiting factor for some companies to produce their products (The Industrial College of the Armed Forces, 2005).

In 1988, there was a reduction in military personnel leaving for the enticing high-tech civilian job market, and a recommendation from the Air Force Blue Ribbon Panel that resulted in the technical degree requirement being eliminated for those in space operations positions. The recommendation also included the "operationalization" of space. The lack of a technical degree requirement brought about a significant loss of the existing technically educated space operators (Staats & Abeyta, 2005). Operationalization means a focus on operations instead of research and development (Staats & Abeyta, 2005). The focus on operations means the Air Force can focus more on training, procedures, and logistics instead of areas where a graduate-level education is needed (Staats & Abeyta, 2005).

A greater focus on training and logistics, and away from continuing education, has increased the already existing problem of the lack of a workforce skilled in the STEM (science, technology, engineering, and mathematics) field. This lack exacerbates the national security issue (Pollack, 2005). The threat to national security is not recent. In 2001, the Commission to Assess U.S. National Security Space Management and Organization recognized the national security threat. Its recommendation was to promote and protect the nation's interest in space, and stressed the importance of a formal technical education due to the many non-routine operations requiring the need for creativity and insight. Specific recommendations included returning the focus on technical education in space-related science, engineering, application, theory, and doctrine (Commission to Assess United States National Security Space Management and Organization, 2001).

Beyond national security, a workforce without the proper knowledge, skills, and competencies impacts the ability of a company to be innovative in developing new products and procedures. Companies are looking to their scientists and engineers to take them to the next level; employees with the right competencies are better able to make those leaps forward (Wuim-Pam, 2014). However, if positions are left open, the existing employees are overtasked with the day-to-day business without the time to devote to product improvements (Giffi et al., 2015).

The ability to hire employees who are trained with applicable knowledge and skills is of high importance to the commercial space industry, and there is a measurable cost associated with the hiring of an employee who does not possess these skills. A new employee who does not possess the required knowledge is more likely to leave their position (Liu et al., 2018). Unfortunately, turnover occurs after significant investment from the company to onboard new employees. On average, it takes 94 days to recruit someone in the engineering and scientist fields in the manufacturing industry (Giffi et al., 2015). That is compared to 70 days for skilled production workers and 48 days for all other workforce areas (Giffi et al., 2015). The time it takes to hire someone is money lost. The cost of hiring a new employee is beyond simple salary costs. Training costs, interviewing costs, advertising costs, and productivity loss must also be included to understand the total investment in time and money that is part of the hiring process. As an example, Zappos CEO, Tony Hsieh, estimates that bad hires have cost his company over $100 million (Wei, 2010). Additionally, the money drain does not end when the employee shows up for work on the first day. It can take two or three years to get a new employee to a "desired level of effective productivity" (U.S. Department of Commerce, 2014, p. 41). That means every worker who has been on the job for less than two years is costing the company money.

The working environment in many of the current commercial space industry companies includes long hours, short timelines, and high pressure. Human resources and hiring managers do not have the freedom or resources to hire and fire employees at a rapid pace. The stakes are high for every decision. Hiring employees who are prepared, skilled, and knowledgeable reduces the risk for companies. Turnover has a measurable impact on the financial bottom-line, and the need to reach and retain economic competitiveness drives employers to "seek to hire individuals who come already equipped with skills and values required to do the job" (Hendrick & Raspiller, 2011, p. 896).

A major concern of the manufacturing industry is the aging of its workforce (Giffi et al., 2015). Much of the industry today is filled with baby boomers, who were born between 1946 and 1964. Their retirement is imminent; estimates range for when the main egress of baby boomers from the industry will occur. Many retirements were between 2008 and 2014. In 2003, 54% of the engineer and scientist workforce was over 45 years old and 33% of them were able to retire within five years (Peeters, 2003). Most were able to retire by 2014 (Doule & Peeters, 2009). While the number of baby boomers who were employed in the manufacturing industry had been reduced between 2002 and 2013, there were still approximately 46 million in the workforce (see Figure 2).

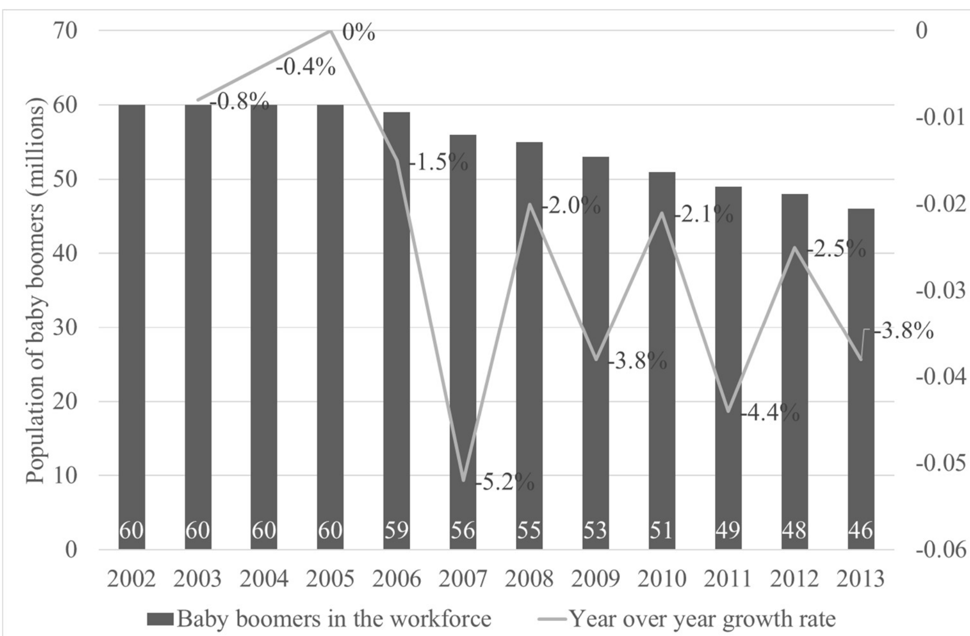

Figure 2. Baby boomers (born 1946-1964) employed in manufacturing industries (Giffi et al., 2015).

The relative inability for the space industsry to compete with large high-tech companies can have some unfortunate unintended consequences. The end of the Apollo and shuttle programs resulted in a reduced number of people being hired at NASA. This reduction in hiring suggests that the remaining workforce continues to age (Doule & Peeters, 2009). The number of engineers and scientists in the 45-54 year-old age range in 2009 was much higher than in other age groups (see Figure 3). Without new programs to maintain or increase the previous level of the industry, there is not an influx of a younger workforce and aging continues (Peeters, 2003).

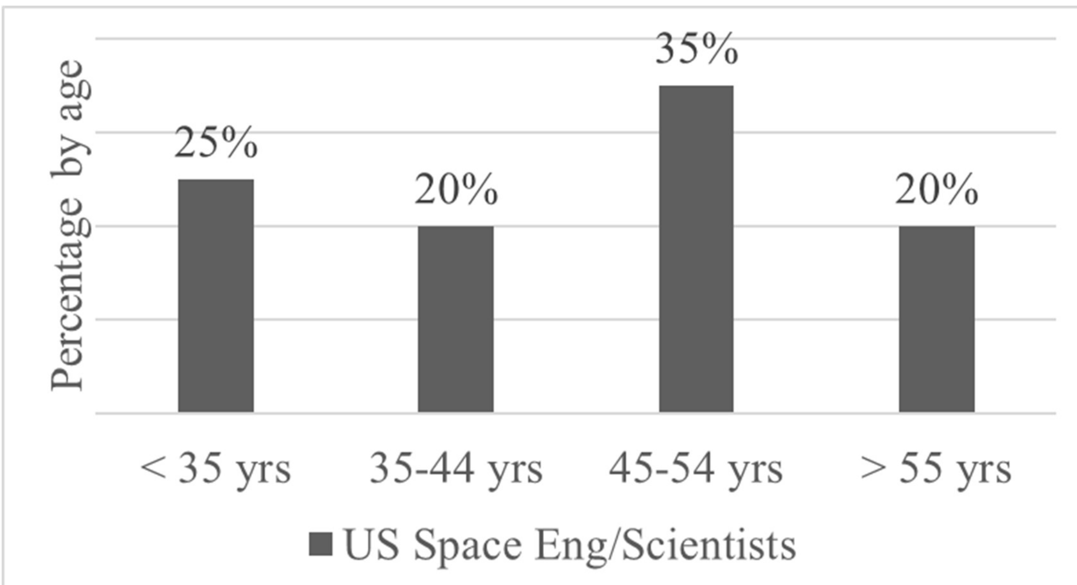

Figure 3. Age of US space engineers and scientists (Doule & Peeters, 2009)

Aerospace companies are having a difficult time hiring trained workers. Traditional aerospace companies are viewed as being "vast, hierarchic bureaucracies with aging workforces and mounting legacy costs" (Westphal, 2015, p. 51). The result is that technically skilled talent is finding it advantageous to work at more glamorous high-tech companies such as Google, Amazon, and clean energy companies (Westphal, 2015). The appeal is even greater when the other high-tech companies are viewed by some as having more "attractive remuneration packages" (Peeters, 2003, p. 839).

Competencies in the Aerospace and Manufacturing Industries

The Committee on Meeting the Workforce Needs for the National Vision for Space Exploration (2007) studied the NASA workforce in 2005 and 2006. Their task was to identify the needed skills to successfully execute the national Vision for Space Exploration established by President George W. Bush in 2004. The committee found that NASA lacked a workforce skilled in program management, systems engineering, integration engineering, and development of large human spaceflight systems. This is not a list of all the critical skills needed to work at NASA, just those skills that were identified as highly needed and most critical at that time. In addition to the few critically needed competencies, the committee also included a complete list of 110 existing competencies at NASA and the number of employees possessing those competencies (see Appendix A). There is no indication of importance or criticality on the list, but the list does provide an insight into the types of competencies needed at NASA. Unfortunately, the competencies on the list are broad categories, not specific skills that can be translated easily into curriculum recommendations.

While the European space industry is not the same as the U.S. industry, the types of skills needed to design, manufacture, and produce space capable systems are the same around the world. Doule and Peeters (2009) surveyed the European space industry to determine the types of skills needed to succeed. There were questions on a multitude of different topics including hard and soft skills, demand, and future education areas. They found that hard skills categorized as explicit knowledge and rational processes are in high demand; however, they found that other non-technical disciplines such as business management, policy, and law are increasing in demand. When it comes to soft skills, Doule and Peeters found that analytical/conceptual thinking, communication, creativity, motivation, and teamwork were most often mentioned or assumed to be present in any future workforce (Doule & Peeters, 2009).

The commercial space industry, like many other industries, is becoming increasingly global. Many industries are looking beyond their country's borders to broaden their customer base and find new suppliers. International expansion brings a new set of challenges to any company. Their employees must be well versed in more than just their technical knowledge. Employees must also understand the intricacies of interacting with people from other cultures. Knowledge of the language is insufficient; there must also be an increase in intercultural and interdisciplinary skills (Doule & Peeters, 2009; Peeters, 2003).

Dubikovsky et al. (2017) examined the knowledge desired by the commercial space industry. The study sent two surveys to both students in an aeronautical engineering technology program and alumni employed in the commercial space industry. The first survey was designed to determine a list of desired knowledge topics. The second survey asked participants to rate the desirability of the topics on a Likert-type scale with values between zero and five. A score of zero indicated the topic was unimportant; five was very important. The surveys were administered in the classroom to 80 students and emailed to four alumni. The results of the survey yielded a list of 25 topics. The topics and their associated rankings are included in Figure 4.

Mehta (2013) completed a similar study. He examined the needs of the commercial space industry from the perspective of creating a curriculum for a bachelor's program in commercial space operations. His approach was to survey participants from "commercial space companies, organizations, and government agencies" (Mehta, 2013, p. 33). The number of

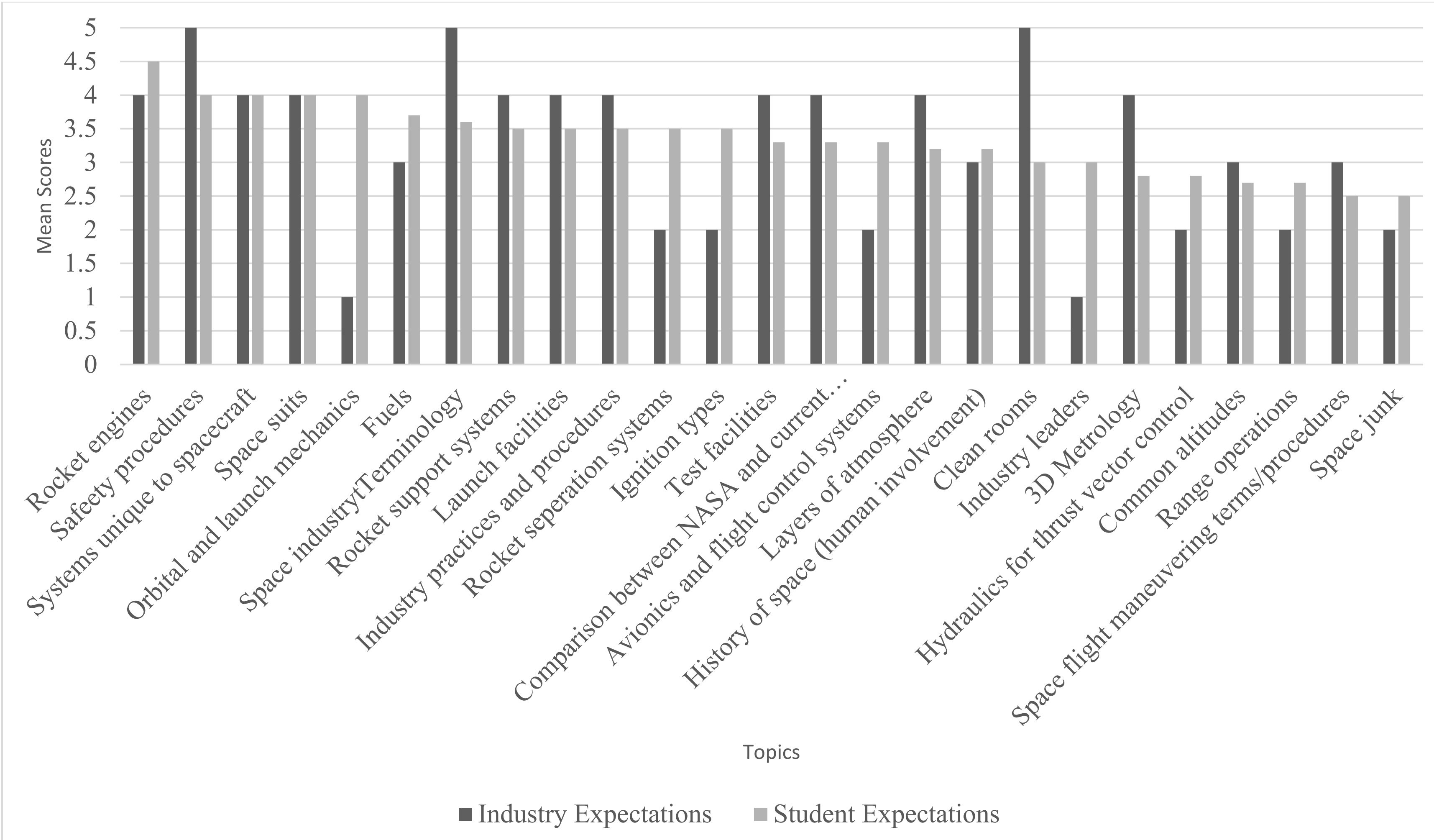

Figure 4. Comparison of topic rankings between commercial space industry professionals and aeronautical engineering technology students (Dubikovsky et al., 2017)

completed and returned surveys were *n* = 22. The respondents (*n* = 84) were asked to rate how suitable 17 topics were for inclusion on a core commercial space operations program.

The 17 topics were spacecraft systems, propulsion, orbits, space policy and law, satellite applications, life support systems, commercial space programs, space radiation, microgravity, space history, space communications, human factors, human physiology, space manufacturing, space stations, habitation outposts, and military space operations. The respondents were asked to rate each subject on a Likert-type scale with responses of “strongly agree”, “agree”, “disagree”, and “strongly disagree”. The means reported were from 2.65 to 3.67 on a 5.0 scale. Essentially, all topics were rated to be at least somewhat important.

Not all commercial space education programs are focused on the traditional college student seeking a degree or an employee seeking further training. There are options for those who have a range of interest and training in commercial space in both technical and non-technical positions. For example, those who have an interest in space or work in space companies in non-technical positions do not likely need in-depth training in the industry and operational environment

One source of training is SpaceEd. SpaceEd is an organization that provides accessible, online training for three groups of people (Faddoul, 2015). The first group is those who have no link to the space industry, but want to become more knowledgeable regarding the subject when reading the news or watching television. They are offered courses that provide basic information on space, astronomy, and space missions (Faddoul, 2015). The second group of people is those who may work at a space company, but they work in non-space technology-focused positions such as secretaries, accountants, and public relations (Faddoul, 2015). They are offered courses in space travel and space operation systems. The final group includes those with a background in some other science or disciple, but they are combining their specialty with a space focus. This may be someone in astrobiology or astrosociology who requires more specialized training, but has no need to pursue a traditional post-secondary degree.

For those who intend to enter the commercial space workforce as an aerospace technician, there is an established curriculum that leads to an industry-accepted certification. SpaceTEC is the National Resource Center for Aerospace Technical Education (SpaceTEC: Who we are, n.d.). This certification is the only performance-based certification currently recognized by the FAA for aerospace technicians. It is offered at 13 colleges: Allan Hancock Community College, Antelope Valley Community College, Brevard Community College, Calhoun Community College, Community College of the Air Force, Community College of Denver, Delgado Community College, Dona Ana Community College, Edmonds Community College, Embry Riddle Aeronautical University, Tarrant County College District, Thomas Nelson Community College, and Tulsa Technology Center (SpaceTEC: Aerospace curriculum, n.d.).

These colleges use an established curriculum of competencies for preparing students to become an aerospace technician in the commercial space sector. Since the certification is for an aerospace technician, the six competencies are focused on shop floor practices. The six knowledge and skill areas include: (a) applied mechanics, (b) aerospace safety, (c) basic electricity, (d) introduction to aerospace, (e) materials and processes, and (f) tests and measurements (SpaceTEC: Welcome, n.d.). There are performance standards under the competencies providing the specifics and details of what is required for the students to obtain a certification as an aerospace technician (see Appendix B). For example, to demonstrate knowledge of materials and practices, a student must be able to demonstrate knowledge of corrosion control and metallurgy (SpaceTEC: Core certification competencies, n.d.).

The manufacturing industry is also challenged by the lack of skills found in the workforce. In research conducted for the Manufacturing Institute and Deloitte in 2015, executives reported there were major deficiencies in four broad categories: (a) Executives reported that 70% of their workforce was insufficiently skilled in technology and computer skills, (b) 69% were deficient in problem-solving skills, (c) 60% were deficient in math, and (d) 67% were deficient in basic technical skills (Giffi et al., 2015). Because the workforce is lacking in these basic skills, executives find it difficult to identify and hire qualified candidates.

To better identify the competencies needed, the U.S. Department of Labor (DOL) developed the Advanced Manufacturing Competency Model in 2006, and it was revised in 2010 (U. S. Department of Labor, 2010). The model is depicted as a nine-tiered graphic (see Figure 5) (Department of Labor Employment and Training Administration, 2010). The model is built to easily illustrate how personal effectiveness, academic, and workplace competencies were built on occupational and workplace competencies (Department of Labor Employment and Training Administration, 2010).

There are nine tiers; each is representative of the building blocks for competencies. The bottom three tiers of manufacturing competencies are common across all industries and called the foundational competencies. Tier one, personal effectiveness competencies, are sometimes referred to as "soft skills" and are more challenging to teach or assess. These competencies are common across the home, community, school, and workplace (Department of Labor Employment and Training Administration, 2010). This tier includes items such as integrity and professionalism. Tier two, academic competencies, are directly linked to successful learning in school. These competencies include math, reading, writing, and communication. Cognitive

Tier 9: Occupation-Specific Competencies #1							
Not completed by DOL							
Tier 8: Occupation-Specific Competencies #2							
Not completed by DOL							
Tier 7: Occupation-Specific Competencies #3							
Not completed by DOL							
Tier 6: Management Competencies							
Not completed by DOL							
Tier 5: Industry-Sector Technical Competencies							
Not completed by DOL							
Tier 4: Industry-Wide Technical Competencies							
Manufacturing Process Design & Development	Quality Assurance/ Continuous Improvement	Maintenance, Installation, & Repair	Supply Chain Logistics	Production	Sustainable & Green Manufacturing	Health, Safety, Security, & Environment	
Tier 3: Workplace Competencies							
Business Fundamentals	Teamwork	Adaptability/ Flexibility	Marketing & Customer Focus	Problem Solving & Decision Making	Working with Tools & Technology	Checking, Examining, & Recording	Sustainable Practices
Tier 2: Academic Competencies							
Science	Basic Computer Skills	Mathematics	Writing	Communication: Listening & Speaking	Critical & Analytic Thinking	Information Literacy	
Tier 1: Personal Effectiveness Competencies							
Interpersonal Skills	Integrity	Professionalism	Initiative	Dependability & Reliability	Lifeline Learning		

Figure 5. Department of Labor advanced manufacturing competency model (Mandelbaum, Hurt, Patterson, & Shea-Keenan, 2012)

functions and thinking styles that are part of this tier are applicable to most industries and occupations (Department of Labor Employment and Training Administration, 2010). Tier three of the model focuses workplace competencies including teamwork, adaptability, planning, and organizing. These competencies reflect motives and interpersonal styles. Tier four includes the manufacturing industry-wide competencies. These technical competencies include production, supply chain logistics, and quality assurance (Department of Labor Employment and Training Administration, 2010).

Tiers five through nine were not developed by the Department of Labor (DOL) as they are specific to a particular industry sector and occupation. In 2012, the Society of Manufacturing Engineers (SME) built on the work previously completed by the DOL and the Department of Defense (DOD), specifically the functional leader of Production, Quality, and Manufacturing (PQM) acquisition career field to finish the uncompleted tiers. The purpose was to create the aerospace and defense manufacturing competency model (ADMCM) (Mandelbaum, Hurt, Patterson, & Shea-Keenan, 2012). The model encompasses both the government and private industry workforce throughout the supply chain, however, not the shop floor workforce (Mandelbaum et al., 2012).

The ADMCM makes minor changes in tiers two and three to the model. First, engineering and technology were added as a competency to tier two. Second, innovation and invention were added to tier three. Additional competencies are included in bolded and italicized text (see Figure 6).

The development of the ADMCM created competencies for tiers five through nine (see Figure 7). Tier five is the aerospace and defense-specific competencies (Mandelbaum et al., 2012). The competencies in tier five represent those skills that individuals new to the

Tier 4: Industry-Wide Technical Competencies								
Manufacturing Process Design & Development	Quality Assurance/ Continuous Improvement	Maintenance, Installation, & Repair	Supply Chain Logistics	Production	Sustainable & Green Manufacturing	Health, Safety, Security, & Environment		
Tier 3: Workplace Competencies								
Business Fundamentals	Teamwork	Adaptability/ Flexibility	Marketing & Customer Focus	Problem Solving & Decision Making	Working with Tools & Technology	Checking, Examining, & Recording	Sustainable Practices	***Innovation & Invention***
Tier 2: Academic Competencies								
Science	Basic Computer Skills	Mathematics	Writing	Communication: Listening & Speaking	Critical & Analytic Thinking	Information Literacy		***Engineering & Technology***
Tier 1: Personal Effectiveness Competencies								
Interpersonal Skills	Integrity	Professionalism	Initiative	Dependability & Reliability	Lifeline Learning			

Note: Emphasis, bold and underline, provided to identify skills added by the Department of Labor.

Figure 6. Updated Department of Labor advanced manufacturing competency model to include additional competencies developed during ADMCM creation (Mandelbaum et al., 2012).

Tier 9: Occupation-Specific Competencies #1								
Audit/Review Planning Execution, & Documentation	Proactive Risk Identification	Realized Risk Management	Analysis, Corrective Action, Closure, Sharing of Lessons Learned					
Tier 8: Occupation-Specific Competencies #2								
Pre-Award Support Activities	Source Selection & Contract Negotiation	Post-Award Support Activities						
Tier 7: Occupation-Specific Competencies #3								
Acquisition Planning	Manufacturing and Quality Planning	Special Tooling & Test Equipment/ Government Furnished Equipment		Production Line Shutdown/Restart				
Tier 6: Management Competencies								
Equipment/Tools Development	Production System Development	Automation						
Tier 5: Industry-Sector Technical Competencies								
Aerospace & Defense Fundamentals	Manufacturing & Production Processes	Supplier Technical Management	Enhancing Producibility	Design & Development	Technical Cost Estimating Analysis, & Control	Support for Product Maintenance		
Tier 4: Industry-Wide Technical Competencies								
Manufacturing Process Design & Development	Quality Assurance/ Continuous Improvement	Maintenance, Installation, & Repair	Supply Chain Logistics	Production	Sustainable & Green Manufacturing	Health, Safety, Security, & Environment		
Tier 3: Workplace Competencies								
Business Fundamentals	Teamwork	Adaptability/ Flexibility	Marketing & Customer Focus	Problem Solving & Decision Making	Working with Tools & Technology	Checking, Examining, & Recording	Sustainable Practices	***Innovation & Invention***
Tier 2: Academic Competencies								
Science	Basic Computer Skills	Mathematics	Writing	Communication: Listening & Speaking	Critical & Analytic Thinking	Information Literacy		***Engineering & Technology***
Tier 1: Personal Effectiveness Competencies								
Interpersonal Skills	Integrity	Professionalism	Initiative	Dependability & Reliability	Lifeline Learning			

Figure 7. Aerospace and defense manufacturing competency model tiers five through nine (Mandelbaum et al., 2012).

manufacturing industry may not be aware of due to their education and work experience (Mandelbaum et al., 2012). Tier five includes aerospace and defense fundamentals, supplier technical management, and technical cost estimating analysis and control. Tier six is facility and equipment development competencies. This tier includes such items as automation and tool development. Tier seven is planning and support. This is where acquisition, planning, manufacturing planning, and production line startup and shutdown are included. Tier eight includes the contracting support competencies such as pre- and post-award support activities and source selection. Lastly, there is tier nine, risk management. Competencies in this area include audit and review planning, proactive risk identification, and realized risk management.

Qualitative Descriptive Studies

Qualitative descriptive studies are popular with health science researchers (Hsieh & Shannon, 2005). They are useful for complex issues and with populations that are generally underrepresented (Jiggins Colorafi & Evans, 2016). Qualitative descriptive studies are "fundamental" qualitative studies (Sandelowski, 2000, p. 335). Their purpose is a "comprehensive summarization, in everyday terms, of specific events by individuals or groups of individuals emerging from naturalistic inquiry (Lambert & Lambert, 2012). Qualitative descriptive studies provide "factual responses to questions about how people feel about a particular space, what reasons they have for using features of the space,…" (Jiggins Colorafi & Evans, 2016, p. 17).

According to Sandelowski (2000), qualitative descriptive studies are differentiated from other types of qualitative studies in key ways. It is not an "adaptation" of other categories of qualitative studies such as grounded theory, phenomenology, or ethnography (Jiggins Colorafi & Evans, 2016; Sandelowski, 2000, p. 335). Also, because it is less interpretive, researchers do not move as far from their data as other categories (Sandelowski, 2000). This minimal movement from the data increases the likelihood that multiple researchers will agree (Jiggins Colorafi & Evans, 2016). Additionally, no abstract rendering of the data is required. It is not considered a way to begin other types of qualitative research, but a valuable product in and of itself.

Qualitative studies, if not reported well, can result in a study that does not seem trustworthy or objective. To ensure a trustworthy and authentic study, there are five standards that must be met including objectivity, dependability, credibility, transferability, and application (Jiggins Colorafi & Evans, 2016; Lincoln & Guba, 1985). Objectivity or confirmability is the relative neutrality and "freedom" from researcher bias (Jiggins Colorafi & Evans, 2016, p. 23). There are four ways to increase the objectivity of the study (Jiggins Colorafi & Evans, 2016): (a) describe in detail the methods and procedures, (b) create an audit trail that includes the sequence of data collection, analysis, and presentation methods, (c) report personal assumptions and bias, and (d) make the study available to collaborators for review.

Dependability, or reliability, is the consistency in procedures across participants, methods, and time (Jiggins Colorafi & Evans, 2016). Multiple methods are used to increase dependability. Those methods encompass consistency in data collection, use of the same investigator, standard interview procedures and questions, and developing interview questions during preliminary work (Jiggins Colorafi & Evans, 2016).

Credibility, or internal validity, is the idea that the findings of the study make sense or match reality (Jiggins Colorafi & Evans, 2016; Merriam & Tisdell, 2016). Essentially, ensuring the data collected are accurate, credible, transferable, dependable, and confirmable (Lincoln & Guba, 1985). Three methods increase credibility including the use of context-rich descriptions, asking other researchers to review the study for the ring of truth, and providing a comprehensive account of the study (Jiggins Colorafi & Evans, 2016). Member checking or respondent validation is another method for building validity. This is where the participants are asked to review the data throughout the process (Lincoln & Guba, 1985; Merriam & Tisdell, 2016). Transferability, or external validity, is the idea that the study has a larger application to other studies or settings (Jiggins Colorafi & Evans, 2016). Jiggins Colorafi and Evans (2016) discussed two ways to increase transferability. The first is providing a detailed description of the participants. The second is to provide alternate ways the findings of the study could be tested.

A study's application can be increased through publication. The application is knowing what the study will do for its participants and consumers (Miles, Huberman, & Saldaña, 2014). A qualitative study may suggest and inspire further research, changes to policy, and changes to a product (Jiggins Colorafi & Evans, 2016).

Summary

Many challenges face the commercial space industry, but an aging workforce is partially responsible for the vacancies. Knowledge critical to the commercial space industry is difficult to identify and validate when the research is not focused on specific job positions. While there is a great deal of overlap among organizations and educational institutions, there is very little consolidation and differentiation among competencies; participants in studies are not forced to prioritize or compare competencies. This leads to a situation where participants ask for everything they want without regard to resources. It is difficult for this information to be useful to organizations or educational institutions because participants do not understand the relative importance of each competency. Educational institutions may choose to focus on competencies that are of lesser need. A focus on unnecessary competencies is detrimental to critical industry needs.

CHAPTER 3. METHODOLOGY

This chapter describes the research design of the study. It includes examinations of the rationale and conceptual and theoretical frameworks. It also includes the population and sample, instrumentation, data collection, data analysis, and procedures.

Rationale

To better understand the training and education experiences of entry-level manufacturing engineers and identify the technical competencies (knowledge, skills, and dispositions) for entry-level manufacturing engineers, an exploratory qualitative descriptive methodology was chosen to ascertain the expectations of industry professionals. The purpose of a qualitative descriptive research study was to provide a comprehensive summary of specific events experienced by an individual or a group in a simple and logical manner (Lambert & Lambert, 2012). Qualitative descriptive research was commonly used in the health sciences, in part, because it provided truthful answers to questions about how people felt about the use, reasons, and factors that help or hinder the use of a particular space (Jiggins Colorafi & Evans, 2016). Another characteristic of qualitative descriptive research focused on "low interference"; the findings did not require as much "logical reasoning" to move from data to conclusions (Jiggins Colorafi & Evans, 2016, p. 17). There was less interpretation of the data to reach the findings (Lambert & Lambert, 2012; Sandelowski, 2000, 2010).

Since there was a gap in the research and literature related to the competencies for manufacturing engineers in commercial space, there was limited information. A qualitative descriptive study was preferred to ensure that the data were reflective of the participant's experiences in the absence of previous research. This study began to build the body of research by interviewing eight participants who were manufacturing engineers in the commercial space industry. These interviews provided an opportunity for the participants to explain their experiences and perspectives toward the needed technical competencies and educational experiences. The data from the interviews built a foundation of knowledge for both the commercial space industry and academia to derive future requirements and curricula.

Theoretical Framework

The Model of Domain Learning (MDL) was used as the theoretical framework in this study (Alexander, 2003). The model of domain learning included four primary areas: expertise in academic areas, stages in domain learning, subject matter knowledge, and interest in expertise development (Alexander, 2003). This study was concerned chiefly with the primary area of domain learning in the context of manufacturing engineering in commercial space. In MDL, there were three stages of domain learning or expertise development: acclimation, competence, and proficiency/expertise (Svinicki, 2008). Learners started at the acclimation stage with limited knowledge. Learners at this stage have little personal knowledge to help them focus on the information that was important to learn versus what was interesting for them to learn (Svinicki, 2008). It was common for students to be in this stage when they started college.

In the acclimation stage, learners may have a narrow interest in commercial space. They may enjoy learning about the vehicles and launches of SpaceX. However, learners are unfamiliar and possibly uninterested in learning about more detailed information such as the legislation that leads to the establishment of SpaceX and companies like it, or with the importance of Robert Goddard to the history of spaceflight. Their knowledge is very focused on areas where they have a specific interest. Potential employees at this stage are not expected to be of interest to employers, as the knowledge base is not adequately broad or in-depth to be more useful to the company than someone without any domain-focused knowledge.

After acclimation, learners progress to competence. At this stage, learners have begun to organize their knowledge and apply deeper level learning strategies. Personal interest is raised in the learners, meaning there is less dependence on “situational features of the environment” (Alexander, 2003, p. 12) and are able to advance into deeper learning. Knowledge of the topic broadens to include topics beyond the initial ones that inspired interest.

Learners in the acclimation stage are more valuable to employers. Learning and knowledge have reached a point where they are able to accomplish "mundane" tasks unsupervised (Svinicki, 2008, p. 22). In addition, the efficiency of accomplishing routine tasks faster allows the new employee to work on more advanced and novel tasks instead of spending time on tasks that do not contribute to the greater body of knowledge.

Finally, learners achieve the proficiency/expertise level. A key characteristic of learners at this stage is they have progressed to contributing to the new knowledge of the domain (Alexander, 2003). Their high knowledge base, personal interest, and ability to problem solve imply that they are expected to be of high value to employers.

Conceptual Framework

Characteristics of job performance, commitment to the job, and the personal satisfaction derived from the job are key for success in any industry, including the commercial space industry (Hammed & Waheed, 2011). The conceptual framework of this study consists of the interaction among technical skills, job satisfaction, performance, and commitment to exceptional manufacturing support engineers. This study is an exploration of the training, educational experiences, and technical competencies of entry-level manufacturing engineers in the commercial space industry. While the current literature related to the specific skill set required for manufacturing engineers is limited, there is literature that links skills and competencies to job success (Hammed & Waheed, 2011).

The multiple characteristics are important to companies because there are multiple competencies the company is seeking in their exceptional employees. Additionally, they are attempting to avoid the additional costs in funds and schedule delays by reducing employee turnover. With successful employees, a company is in a better position to not only meet its current commitments, but also have the resources to expand into new markets or improve existing products (Giffi et al., 2015; The Industrial College of the Armed Forces, 2005).

A conceptual framework was developed for this study. The framework was based on the relationship between the variables of technical skills, job satisfaction, performance, and commitment (see Figure 8). The interaction among these characteristics established the conceptual framework and their influence on the characteristics of an exceptional commercial space manufacturing engineer.

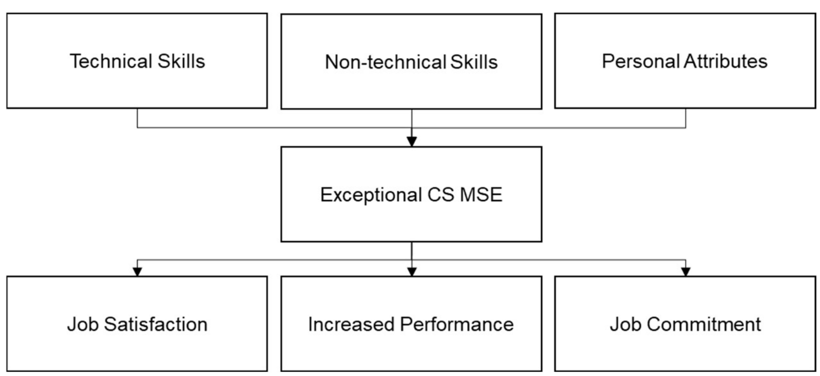

Figure 8. Characteristics in the conceptual framework: Skills influence on exceptional manufacturing engineers

Research Design

This qualitative descriptive study explored the training and educational experiences of entry-level manufacturing engineers and identified the required technical competencies (knowledge, skills, and competencies) for entry-level manufacturing engineers. The purpose of qualitative descriptive studies is to provide a "comprehensive summary of an event in the everyday terms of those events" (Sandelowski, 2000, p. 336). Qualitative descriptive studies pursue accuracy and descriptive validity for a particular phenomenon (Sandelowski, 2000). For this study, the phenomenon was the educational experiences of entry-level manufacturing engineers in the commercial space industry through pilot and field studies.

The purpose of the preliminary or pilot study was to inform the process and assist in identifying the relevant lines of questioning (Yin, 2003). A pilot study ($n = 1$) was completed to inform the interview protocol for the remaining interviews. Data from the pilot study were collected, but they were not included in the data set.

Following the pilot study, a field study was completed by conducting interviews with eight participants ($n = 8$). When necessary, email was used for follow-up communications. Email communication allowed for ease of response since participants were industry professionals with limited time and resources.

A document review was completed to inform and enhance the interview responses and findings. The documents reviewed were industry and government reports that identified the needed skills in the manufacturing industry. Additionally, documentation from education accreditation bodies reporting on the curriculum for manufacturing engineering and manufacturing engineering technology programs was also reviewed.

Population and Sample

Compared to the entire aerospace and defense industry, the commercial space sector is very small. According to the Aviation Week World Aerospace Database, the total number of aerospace and defense companies around the world is more than 12,000; there are approximately 7,700 located in the United States (Aviation Week, 2018). Additional analysis of the data is necessary to understand the number of commercial space companies. The World Aerospace Database lists 91 global commercial space manufacturers; of which 31 are in the United States (see Appendix C). The sizes of the companies vary greatly, some with fewer than 10 employees. A few companies have as many as 18,000 employees.

Purposive sampling was used to discover and understand the population (Merriam & Tisdell, 2016). In qualitative descriptive research, sampling selection is open to almost any purposive sampling technique (Cohen, Manion, & Morrison, 2007; Jiggins Colorafi & Evans, 2016). The participants for this study were selected based on their work experience as manufacturing engineers in the commercial space industry. The criteria used to determine entry-level versus expert-level employees were adopted through two different reviews of job postings and their requirements for manufacturing engineers. One review was completed for expert-level manufacturing engineers. A second review was completed for entry-level manufacturing engineers.

To establish criteria for expert-level manufacturing engineers, job postings were reviewed where terms such as principal or lead were part of the job title. To establish the years of experience needed for expert-level engineers, job postings from Boeing (Boeing, 2020), SpaceX (SpaceX, 2020), Northrop Grumman (Northrop Grumman, 2020), and Blue Origin (Blue Origin, 2020) were reviewed. Examples of the jobs and the years of experience are listed in Table 1. For this study, an expert-level manufacturing engineer was defined as one who had generally the minimum number of years of experience, three years, as a manufacturing engineer working in the commercial space industry.

Table 1. Sample of Expert-Level Job Postings and Years of Experience Required

Company	Job Title	# years of experience
Boeing	Manufacturing Engineer - Mid Level	5
Blue Origin	Manufacturing Engineer II	3
SpaceX	Lead Manufacturing Engineer	3
Northrop Grumman	Principal Manufacturing Engineer	9

The approach to determine the years of experience needed for an entry-level manufacturing engineer mirrored that for expert-level manufacturing engineers except the job titles did not include qualifying terms such as lead or principle. A review of job postings from Boeing (Boeing, 2020), SpaceX (SpaceX, 2020), Northrop Grumman (Northrop Grumman, 2020), and Blue Origin (Blue Origin, 2020) were reviewed. A sample of job postings from the review is presented in Table 2. The work experience for an entry-level manufacturing engineer was defined as one to three years of experience in the commercial space industry.

Table 2. Sample of Entry-Level Job Postings and Years of Experience Required

Company	Job Title	# years of experience
Boeing	Manufacturing Engineer (Assembly and Installation)	2
SpaceX	Manufacturing Engineer	0
SpaceX	Manufacturing Engineer	1
Blue Origin	Manufacturing Engineer	2
Northrop Grumman	Manufacturing Engineer	2

A combination of expert-level and entry-level manufacturing engineers was chosen to participate in the study. There were five expert-level and three entry-level manufacturing engineers who participated, n = 8. A summary of the breakdown between pilot, expert-level, and entry-level manufacturing engineers is presented in Table 3. A summary of the participants, their pseudonyms; and years of experience in manufacturing engineering and commercial space (CS) is presented in Table 4. The participants' names were changed, but their gender identity was not.

Table 3. Category Breakdown of Experience

Category	Experience	Sample Size	Experience Reported by Participants
Pilot	>3	1	29 years
Entry-level	≤ 3 years	3	6 months to 2 ½ years
Expert-level	> 3 years	5	4 years to 12 years

Table 4. Participants and their Experience

Participant Pseudonym	Experience Level	Commerical Space Industry Experience	Manufacturing Engineer Experience
Kevin (pilot)	expert-level	29 years	29 years
Larry	expert-level	20 years	4 years
Julia	expert-level	18 years	9 years
Adam	expert-level	12 years	12 years
James	expert-level	9 years	9 years
Lisa	entry-level	2 1/2 years	1 year
Ben	entry-level	4 1/2 years	2 ½ years
Nick	entry-level	1 year	1/2 year
Zane	expert-level	6 years	6 years

Kevin	Expert-level	Kevin participated in the pilot study and his data were not included in the study. He is currently employed at a large aerospace company in the southeast United States as a liaison engineer. He has almost 30 years of experience in the commercial space industry.
Larry	Expert-level	Larry is currently employed at a large aerospace company in the southeast United States as a systems engineer. He has almost 20 years of experience in the commercial space industry.
Julia	Expert-level	Julia is currently employed at a medium-sized aerospace company located in the southwest United States. Her current job title is Engineering Specialist. She has almost 20 years of experience in the commercial space industry.
Adam	Expert-level	Adam is currently employed at a large aerospace company located in the northwest United States. His current job title is liaison engineer. He has approximately 13 years of experience in the commercial space industry.
James	Expert-level	James is currently employed at a large aerospace company located in the northwest United States. His current job title is a manufacturing engineer. He has approximately nine years of experience in the commercial space industry.
Zane	Expert-level	Zane is currently employed at a large commercial space company as a systems engineer. He has worked for four different commercial space companies as a systems engineer. He has approximately six and a half years of experience.

Lisa	Entry-level	Lisa is currently a graduate student at a large university in the Midwest. She has approximately two years of experience in the commercial space industry with one year of experience as a manufacturing engineer.
Ben	Entry-level	Ben works for a commercial space company with two years of manufacturing engineer experience.
Nick	Entry-level	Nick is currently employed at a large aerospace company located on the west coast. His current job title is an industrial engineer. He spent six months working at a large commercial space company as a manufacturing engineer.

Although the population for this study is small, the wide range of experience and background of the participants provide a broad perspective to answer the research questions. Each of the participants have some experience as a manufacturing engineer in a commercial space manufacturing program. Job titles may vary among the participants, but the job functions support manufacturing processes at a commercial space company. Beyond that, however, their experience is varied. Some have very little experience beyond their education; regardless if it is aerospace as a whole or only in commercial space. Others have been working in the aerospace industry for almost 20 years. This variation in experience and background is helpful in avoiding a common response to the research questions by the participants.

Instruments

Both the pilot and field studies consisted of interviews using open-ended, semi-structured questions. The basic structure of the interviews for both entry-level and expert-level manufacturing engineers was the same; although, the specific questions for each group were different. Information sheets and interview protocols were developed and the interviews were recorded using audio, only. The information sheets for entry-level and expert-level manufacturing engineers are located in Appendixes D and E, respectively. All the data collected from both entry-level and expert-level manufacturing engineers were combined to create a single data source for analysis.

The interview participant for the pilot study was an expert-level manufacturing engineer. The interview protocol for the pilot study was developed based on the literature review and the researcher's aerospace industry experience. The interview consisted of nine questions (see Appendix F). The first four questions were information gathering about the background of the participant. The remaining five questions pertained to the typical skills or competencies required for a manufacturing engineer, how in-depth they should know or be able to perform those skills or competencies, and the consequences if the employee does not know or have those skills or competencies. Table 5 lists the number of questions based on the expertise level of the participant.

Table 5. Number of Interview Questions by Participant Experience

Category	# Interview Questions
pilot	9
expert-level	8
entry-level	10

The instruments for the pilot study, expert-level, and entry-level manufacturing engineers were different. The results from the pilot study (n = 1) were incorporated into the expert-level manufacturing engineer protocol (see Appendix G). One question was removed and the other questions were clarified based on the response from the pilot participant. The interview questions for the expert-level manufacturing engineers ($n = 5$) focused on their perceptions of the required technical skills needed for entry-level manufacturing engineers. The interview questions for the entry-level manufacturing engineers ($n = 3$) focused on their experiences in education and training. The interview questions also included their perceptions of the required technical skills for entry-level manufacturing engineers (see Appendix H).

Data Collection

Data collection for qualitative descriptive studies "involves minimal to moderate, structured, open-ended, individual or focus group interviews" (Lambert & Lambert, 2012, p. 256). The efforts for this study were focused on not manipulating or interfering with the data (Jiggins Colorafi & Evans, 2016), but accurate listening and recording. For this study, the data were gathered through semi-structured interviews using open-ended questions with individual participants. Follow-up questions, or probes, were based on the participant's responses and not existing theory (Hsieh & Shannon, 2005).

The data were collected through both a pilot study and a field study. A pilot or preliminary interview was completed using one participant and the data collected were not included in the study data. The findings from the pilot study were evaluated for incorporation into the interview protocol to increase the dependability of the study (Jiggins Colorafi & Evans, 2016). Five expert-level and three entry-level commercial space manufacturing engineers from different companies were chosen for the field study. None of the eight participants were used for the pilot study. The researcher knew the connection between the participants and the data they produced, but maintained the information as confidential. The data were de-identified and anonymous to the reader. A summary of the participants and the length of their interviews are located in Table 6.

Table 6. Participant Interview Length

Pseudonym	Experience Level	Length		
		hours	minutes	seconds
Larry	expert-level		14	35
Julia	expert-level		35	21
Adam	expert-level		42	7
James	expert-level		38	39
Zane	expert-level		13	25
Lisa	entry-level	1	8	57
Ben	entry-level	1	10	30
Nick	entry-level	1	9	2
total time		**3**	**169**	**216**
total hours		**5.88**		

The interviews were conducted over the phone and recorded for future transcription. Transcription was completed by the researcher, except in two cases where a transcription service was used. The completed transcriptions were sent to the participants for review and potential revisions.

Data Analysis

Unlike other types of qualitative research, descriptive research derives codes from the data generated through the study (Kondracki & Wellman, 2002; Lambert & Lambert, 2012). Accordingly, the researcher did not develop a codebook prior to the interviews; it was developed after the interviews based on the responses from the participants. The responses were collected using open-ended interview questions, transcribed word for word, coded, and categorized (Jiggins Colorafi & Evans, 2016).

The eight semi-structured interviews were evaluated using two coding cycles to identify themes. The coding methods were derived by combining those discussed by Saldaña (2016) and Braun & Clark (2006). In his book, Saldaña identified 25 types of coding methods that are commonly used for data analysis. The two coding methods used for this study were in vivo and pattern coding. Braun and Clark's method for performing thematic analysis on qualitative data has a six-step process. For steps two and three, coding methods from Saldaña were used to complete the step.

1. Familiarize yourself with the data.
2. Generate initial codes (used in vivo coding method).
3. Search for themes (used pattern coding method).
4. Review themes.
5. Define and name themes.
6. Produce the report.

Step one was to read each of the eight interviews two to three times to gain familiarity with the data (Braun & Clark, 2006). Step two, the first coding pass using in vivo coding was completed. The coding pass focused on each interview and participant individually. Each interview was examined for emerging and unique themes. Themes already understood in the literature were not relied upon; instead, the researcher used the actual words and phrases in the transcriptions. For example, communication could have been a theme; but the literature is already rich with the importance of communication and other soft skills in engineering education. Rather, the focus of the analysis was on the task manufacturing engineers completed as an interpreter between design engineers and technicians. As part of the first coding pass, ideas from each interview were written on cards to assist in future steps. To avoid too many codes, each interview was restricted from four to six main ideas. At the completion of this step, there was a total of 37 unique codes.

Step three used pattern coding to search for themes. Pattern coding groups codes or summaries into a smaller number of themes or concepts (Saldaña, 2016). Unlike other types of qualitative research, descriptive research derives codes from the data generated through the study (Kondracki & Wellman, 2002; Lambert & Lambert, 2012). In step four, the index cards were sorted and combined into common themes. Six themes were identified. In step five the transcriptions were entered into NVivo 12 Pro software and all interviews were coded for the six themes. The use of the software allowed for further review and definition of the themes.

Role of the Researcher and Bias

My education and work experience are similar to some of the interview subjects. My university training was in aircraft maintenance, and I obtained an Airframe & Powerplant certificate from the FAA after graduation with my bachelor's degree. This is similar to several of the participants in the study. The remaining participants have engineering bachelor's degrees.

Similarly, my work experience is comparable to the participants. All of them have experience working in the space industry, but some have also worked in the atmosphere-based aviation industry. My background is in atmosphere-based aviation, not the space-based aerospace industry. My experience in atmosphere-based aviation resembles that of the expert-level participants. However, I worked for almost 19 years in a post-production support function, not in a manufacturing position.

While my experience is similar to the participants, it is not identical, this is advantageous to ensure that any potential bias is reduced. My background is beneficial for understanding the language and context of the participants. However, since my work experience is different, I do not have strongly held pre-existing ideas of what the responses should be. This is not to say I have eliminated all potential biases. To reduce more potential bias, I neither focused on providing suggestions nor was directive in the interviews. I remained mindful that I was merely an observer and recorder. During this study, I served many roles. I solicited the participants, conducted the interviews, recorded and transcribed the data, and coded and identified themes in the data.

CHAPTER 4. FINDINGS

The purpose of this study was to explore the training, educational experiences, and technical competencies of entry-level manufacturing engineers in the commercial space industry. The data were collected through semi-structured interviews with eight participants. This chapter is organized thematically to provide the foundation for discussion of the findings. A list of codes and their relationship to the themes are located in Appendix I.

The six themes identified included: (1) mentoring used as a teaching tool, (2) you're going to be doing pretty good, (3) worst case is millions of lives, (4) understand, be familiar, or proficient, (5) the interpreter or the bridge between the design engineer and the shop floor, and (6) the storyteller or make your data tell a story. The theme of mentoring used as a teaching tool discussed the ways manufacturing engineers are dependent on mentors for information and learning. In the theme of you're going to be doing pretty good reviewed the skills needed to be a manufacturing engineer. The consequences of the bad decisions theme, worst case is millions of lives, discussed the participants' responses in their interviews on the consequences of failure. The theme be understood, familiar, or proficient reviewed the language used by the expert-level participants on the needed depth of knowledge for the required technical skills and competencies. The interpreter theme discussed how the manufacturing engineer is the link between multiple groups, primarily the design engineers and the shop floor. The storyteller theme was about how it is expected that the manufacturing engineer analyzes and communicates a persuasive story with their data to influence the manufacturer and design of the system.

Theme 1. Mentoring used as a teaching tool

This theme reflects the common use among the participants of mentors as teachers. The job of the manufacturing engineer is complex. Formal college or university education is not expected to teach everything the student will need to know for their job. Especially those tasks and processes that are unique to each company. This is not unique to manufacturing engineering. All careers and industries experience this to a certain extent. The participants discuss in their interview experiences where information was lacking and the source for gaining the knowledge was not formalized training, but knowledge transfer from their co-workers. This paradigm sets up an environment where mentoring is a common and established form of learning.

All careers require further education to improve existing skills or learn new ones. Further education and training are expected and can be accomplished through additional formal training in a university setting or company training. Much of the training for manufacturing engineers, however, must be through some form of self-directed learning because as Lisa (entry-level) mentioned in her interview, *"... there are just some things where the information may or may not be available."* [Italics are used to add clarity and emphasis to the participants' words.] Many of the skills a manufacturing engineer needs for their job are not sufficiently addressed in their university education. In our interview, Ben (entry-level) echoed this idea.

> *And I think a lot of my formal education fell short on pretty much analyzing data and understanding the different systems, understanding the fundamentals of different sorts of regressive analysis, different sorts of statistical analysis, that sort of thing.*

Nick (entry-level) also found that the specific knowledge he learned in college provided the basis for further learning once he had the job, "*...that experience in turbines and knowing jet* *engines and that sort of thing was invaluable to get me in the door for learning technical writing and geometric tolerance and design (sic) and that sort of thing-- GD&T,…"* Others found formal training, whether from universities or company training was lacking, and the additional knowledge must be found in other locations. Sometimes those other locations are institutional knowledge gained through others. For example, Adam (expert-level) shared… *"I think we're kind of lost in a sense that we're relying on tribal knowledge and mentors."* When discussing this phenomenon further, Adam discussed how some companies purposefully hire only experienced workers because it quickens the time from hire to productivity as a way to improve the individual's performance.

> *And that's kind of how they've made such great milestones is because they grab people that have come from billions of dollars' worth of research over many years of tribal knowledge and many years of mentoring. They are having a quick transition that they are so successful [sic].*

The use of mentors as a source of knowledge and learning is common among the participants. Sometimes the use of a mentor is to learn a specific skill and provide direction when the path forward is unclear as Ben discussed *"Learn from the guy standing next to you. There was not a lot of training for our specific job."* Nick and Lisa echoed this idea.

> *Nick: Well, I'd say in industry, I think it's important to have a culture where employees are taught how to teach, because you can be like one of my friends at [redacted], he said, "You can be a very professional technical employee at your job, but not being able to transfer those skills and teach people how to use tools or how to use the fundamental discipline you learn in manufacturing and process*

improvement. It's very important to have those people to teach you where to seek out the training and where you need feedback in your job performance,…"

Lisa: I was very lucky that the guy sitting next to me was an experienced manufacturing engineer who also liked to help people. That was pure luck because there are just some things where the information may or may not be available. You just don't even know where to start.

Mentorship in a company provides many benefits to the manufacturing engineer. Mentors provide further training through example or as a knowledgeable resource. They are also accustomed to indoctrinating the manufacturing engineer into the culture of the company and how the manufacturing engineer works in the production environment. In our interview, Nick highlighted the role of the manufacturing engineer as an influencer.

I would say probably… the mentorship. That type of role is very important, I think, because it's important to change the way someone thinks about how things are built, how things are manufactured.

Due to the lack of formalized training, the use of mentors as teachers is common among the participants in this study. The participants found that mentors were helpful in imparting technical knowledge directly or providing advice and direction to locate additional information. Participants found mentors to be invaluable to the success and satisfaction in their jobs.

Theme 2. You're going to be doing pretty good

This theme is named to reflect the fundamental skills the participants felt were necessary for success as a manufacturing engineer. The theme title was chosen from James' observation that if a manufacturing engineer understood certain topics, "you're going to be doing pretty good". When it comes to the technical skills and competencies needed to be a manufacturing engineer, the participants responded with three core technical skill sets that comprised theme number two. The first core idea was related to software skills. Participants felt manufacturing engineers should be familiar with software programs such as LabVIEW or MATLAB specifically. However, employees also needed to become familiar with how other software programs are used to locate information such as parts ordering, workflows, and inspections.

MATLAB, a program from MathWorks, is engineering software used to analyze data and create models. LabVIEW, from National Instruments, is a systems engineering software application for test, measurement, and control of devices. Zane (expert-level) and Ben (entry-level) discussed LabVIEW in their interviews.

> *Zane: I would say tool use definitely, and specifically instrumentation. So being competent in LabVIEW… at least in my experience, because most of the data acquisition that's done during integration is through LabVIEW-enabled transducers, or thermocouples, or things like that…. or why a potential manufacturing engineer would need competency in using LabVIEW devices. It's why they would need to know how to use FARO laser measurement equipment to confirm that the thing that they've done is actually within the spec and tolerance.*
>
> *Ben: Coding. Like Matlab. I did that kind of thing in grad school, but not so much in undergrad. Some sort of coding program would be beneficial due to automation and whatnot. I know that there are some automated replacement machines for carbon that is starting to happen. It'd probably be good to know how to program those or at least work with those.*

In addition to software-related skills, the second core technical skillset the participants identified were mechanically inclined skills. These mechanical inclination skills included basic hand tool usage, optical measurement, or additive manufacturing processes. Adam (expert-level) related his experience and disappointment in the lack of mechanical inclination skills in new manufacturing engineers.

> *More mechanical inclination skills. A lot of these people can't change the oil in their car. They just say I'll just take it to Jiffy Lube. There's a summary right there. I need more out-of-the-box thinkers. I need more mechanical inclination skills. I'm going to tear this thing apart.*

Zane discussed the need for using hand tools and their usage, "…*and general tool use. Knowing how to properly use torque measurement devices, measuring devices of all kinds*." Welding and additive manufacturing were areas that Julia highlighted, "*There are emerging technologies that are of high interest to employers and they are all in aerospace looking for people with hands-on experience with friction stir welding, 3D printing, or I guess additive manufacturing."* Manufacturing techniques and materials were areas that James (expert-level) focused on. He connected those skills to the ability of the manufacturing engineer to do their job better.

> *A deep understanding of machining, milling, lathing, a decent understanding of additive manufacturing. Understanding of exotic metal alloys. [Unknown word], Inconel, titanium, as well as your aerospace-grade aluminum…. if I had a deeper understanding of metals and machining while I was a manufacturing engineer, I could have advised the design engineers better ways to make their parts so that they are assembled easier.*

Zane discussed the need for clean rooms, non-destructive testing (NDT), and inspection requirements. Additive manufacturing is a manufacturing process that builds a part by creating material by layers, as opposed to removing material such as milling or lathing. Zane discussed this in his interview.

> *Understanding cleanliness for oxygen and how to preserve it…. I think something that would probably be important, and will be increasingly important, is competency in additive manufacturing, understanding the limits of the process, and the potential how-to-design for manufacturability for additive, as well as the NDT and the inspection requirements for additive manufacturing. I think that's probably also important and will become increasingly important.*

Hands-on skills and tool knowledge were mentioned by other participants. Since part of the manufacturing engineer's position is working with the technicians on the shop floor, understanding tool usage and how it relates to the technician's job is important. Ben discussed this phenomenon, "*On the technician side you need to know how to throw a wrench around, what kind of tools they use, and (sic) what kind of problems they might come across*." Knowing how to take things apart and the relationship to design is the approach Nick (entry-level) took, "*I think also just having a good hands-on background, being able to understand how things are taken apart, how things are designed and why things are designed the way they are, all very good skills to have*." In addition to tooling, Lisa (entry-level) discussed the prevalence and importance of contamination and clean rooms.

> *A good understanding of the importance of using the right tool in the right situation. You can talk about theory all day long, but the actual using tools, using hardware, understanding how difficult it can be if a screw is stripped. You know how to work [sic] torque wrench and screwdrivers no matter what you're*

building. Just an understanding of how they work and why they are important and how they are applied and the trouble people are going to encounter. …awareness of space hardware is contamination issues. That was not something I had thought about until I was actually there. Silicone is very difficult to remove from hardware. It's especially in electronics when you're using a lot of silicone-based parts... There are rules about what kind of care products you can use, you know hand lotions. You can't use hand lotions with soap with silicone in it. Shampoo with silicone and you might touch your hair and then touch your parts… Lots of manufacturing areas have clean rooms, but a space facility is absolutely going to have a clean room so you have to understand cleanroom protocols.

The third core technical skillset the participants mentioned were methods for evaluating parts or systems. Evaluation could be through measurements in CAD programs, physical measurement using geometric dimensioning and tolerancing, or through other testing methods such as stress testing. Adam put it simply, "*I want them to go through stress analysis.*" Ben echoed his comments and took it a step further by linking it to the need to communicate in the language of a stress engineer.

In my opinion, the basic knowledge to understand design engineers would be to understand CAD modeling and understand some stress analysis…. Stress I don't use as much, but I do think that is useful to know so you could understand the language where some of the stress people are coming from.

The need to understand the use of CAD programs was mentioned by several of the participants. Ben stated that, "*They should probably know at least one CAD program*." In fact, Adam felt it was the second most important thing a manufacturing engineer should know.

I thought about it last night from your information sheet and that's probably one right there if I could publicly speak at a university I'd say, hey learn how to balance your checkbook and then, oh by the way, get some CAD training.

Lisa also discussed the need for software familiarity, including CAD because of the need to interact with engineering drawings and other processes,

Being able to use software on computers because that's how you interact with drawings with CAD. With computer software. And the computer software is not just for the drawings, but also for the planning, the parts ordering, the assigning people to work, the workflows, inspections, keeping data, storing data, record-keeping there's all these different software programs that you have to be able to interact with. Now some of these programs I noticed from when I went from [redacted] to [redacted] they use different programs so I'm not talking about the specific click here, click there, it's an understanding of what kind of information is stored and why and how to access it and understand it and communicate it to other people. So when I say you have to understand software, it's not like learn this one particular software. It's understanding what sort of information is stored, how to store it, what information is important.

Adam wants manufacturing engineers to have geometric dimensioning and tolerancing. His discussion evolved into how GD&T can assist in the critical evaluation of drawings and the design, "*I want them to go through basic GD&T training. Geometric dimensioning and tolerancing,… we evaluate everything at a critical level, but it comes down to the details through basic 101 drawing interpretation*." Lisa also contributed to the idea that drawing interpretation is important for a manufacturing engineer to know, "*That being said, the transferable skills, the overall skills, are being able to read and understand drawings is just absolutely critical.*"

James also expressed a straightforward need for GD&T, and he spoke about how a commercial space situation differs from other manufacturing environments. According to James, this level of understanding GD&T is a path for success as a manufacturing engineer.

> *I think you need to have a deep understanding of machining and GD&T….The aerospace standards are significantly tighter than most other GD&T situations. But cars in automotive you're looking at like 0.0020" would be considered a really tight tolerance. Where aerospace interference fit holes have to align within plus or minus half a thousandths or half a thousandth of an inch. Or you can have patterns that are controlled within 10 or 15 thousandths which is really, really tight. Yeah, I think a certification in GD&T or the best GD&T education you can obtain in the university would be ideal….if you're a GD&T expert, and you have a rudimentary understanding of rockets and rocket systems and propellants. You're going to be doing pretty good.*

While each participant identified many different skills and competencies, in general, participants agreed on the three core technical skills of mechanical skills, software-related skills, and the evaluation of systems and procedures. Each of these categories is an opportunity for further learning for a mechanical engineer.

Theme 3. Worst case is millions of lives

This theme is named because of an expert's response to the question regarding the potential consequences of bad decisions. Julia's (expert-level) response, when asked about consequences, was "worst case is millions of lives." This phrase may be interpreted as a mechanism for emphasizing the potential consequences that extend beyond personal loss to the engineer or corporate losses and may extend to the general public. This phrase serves as a wake-up call to think beyond immediate consequences. Larry (expert-level) in his interview recounted how Chuck Yeager, a test pilot who first broke the speed of sound and other speed and altitude records, used to tell a story about how a mechanic improperly installed a part that resulted in the loss of two lives.

> *There's an old story that Chuck Yeager used to tell about a guy on the F100 line who was installing a part upside down because it was easier for him to do it. But unfortunately, he didn't know that when a person would do a barrel roll with this particular aircraft, I think it was the slots or something on the wing or something of that nature, it would jam because the bolt was in upside down, and he killed two pilots.*

Being a manufacturing engineer is not simple, and it can have a significant impact on others. Every decision a manufacturing engineer makes can have many downstream consequences. The ramifications can be varied and impact the manufacturing engineer, their company, and even, in some cases, the public at large.

One of the more straightforward connections is the one between the manufacturing engineer and their personal consequences if they do not perform their job well. As James (expert-level) said, "*I mean if you don't understand how your system is designed and you're not able to interpret whichever the design intent is, you're not going to succeed at your job.*" Adam (expert-level) discussed some of the remediation activities, "*They'll have to go for training, or they'll get pulled off the program*." Even if there is no remediation, there are still consequences, although, they may be less tangible, as James and Adam mentioned in their interviews.

James: Let's see, if you don't understand how your system works, if you don't understand the properties, you're going to wind up asking silly questions. Well not necessarily silly questions, but you're going to make silly observations that just indicate that you don't know much. Instead of being a resource and an asset to the company and team, people are going to start shying away from you, which is not good for your personal growth. Which is not good for the company because then you're not providing value. It becomes a crummy situation pretty fast.

Adam: Those consequences are severe. They will pull you off. And that goes to say with any job function. If you're a mechanic, and you've made a mistake, we're all human, but if you're making more mistakes… you find your way back to unemployment or some other part of the company if you're incompetent…. Because everyone costs so much money. They just couldn't afford these kind of junior mistakes.

Other consequences could be quality related to where the part or system is unable to conform to the expected configuration. Larry talked about how some of those consequences connect the parts, "*Everything from just not passing qualification or inspection. Having a unit that doesn't conform to its physical configuration audits*." The consequences can be broad and difficult to predict as Zane (expert-level) stated, "*Incorrectly signing off on something that was out of spec, which could have a consequence ranging from requiring rework to having a really bad day on the launch pad.*"

Sometimes the problem can come to light months after the mistake has been made. Delays in recognizing mistakes are problematic and can cascade the repercussions. If you are lucky, the problem is clear, but frequently it is not. James and Julia discussed the delay in identifying problems in their interviews.

James: Through the decisions in the path you go down, the decisions don't become realized until 3 months later. So, if you get off a little bit early on, you can really make a hash of things pretty fast, but you won't know it until it's been 3 months and now you've got three months of bad decisions that need to be corrected in an incredibly rapid fashion.

Julia: And if you find one in test it means you have to de-build your product, go find the issue because chances are you don't even know exactly where the issue is on the test. You just know you had a failure. So, you have explorative manufacturing going on which is time and money. And then you find the anomaly, fix it, and rebuild everything and go into test. So, you get a schedule slip…. And that will cost you weeks to months of your launch schedule.

Sometimes it is difficult to see how a simple mistake made by one manufacturing engineer can result in the death of thousands, if not millions, of people. This is not a fantasy, but an idea that is grounded in reality. Julia laid out the sequence that happens when the manufacturing engineer forgets to ground themselves properly, which causes latent failures. Therefore, when it fails, the satellite no longer fulfills its function, and it can result in the death of a significant portion of the population because an expected and previously existing capability is no longer available.

Worst case is millions of lives. Some of the larger programs that I've had the honor of working on… weather satellites. Hurricane Katrina, for example, is not something that we expect to happen again scientifically… But predictive *analytics and imagery satellite imagery of visible light spectrum and not visible light spectrum and heat and radar and all those things that can give us imagery of what's coming…. and then you accidentally didn't ground yourself before dealing with electronics.*

So, now you have electrostatic discharge face damage on some of your electronics equipment. They can have latent failures and they can fail in orbit and now you have all this infrastructure and you've built and sent the rocket, and you spent, however many, years getting the satellite up and it just turns off. So, you've got no satellite and now you've got a bogey that's floating around in space that's going to float off of its orbit. You can't talk to it, cause the comm system is down. It may float into other satellites. It may float into a space station. It may degrade in orbit and burn up in the atmosphere and all you lost is that one satellite, but you lost the ability to provide a service to the population here on Earth.

Consequences are difficult to predict. Some consequences are delayed and minor. Others are immediate and major. Manufacturing engineers are in a position to cause major, minor, immediate, and delayed consequences. The language the participants used to discuss the importance of knowing the technical skills was primarily related to cost and schedule, but that is not the limit of consequences. As Julia said, when it comes to consequences of bad decisions, the worst case is millions of lives are lost.

Theme 4. Understand, be familiar, or proficient

Some common terms used by the participants to describe the depth of knowledge the manufacturing engineer would need are related to the technical skills, and were used to name the theme, understand, be familiar, and proficient. This theme was built around the results of the three core technical skills: mechanical, software, and evaluation and procedures.

For mechanical skills, such as mechanical inclination, Adam (expert-level) used language that related the skill level to the need for assistance. He said the entry-level manufacturing engineer "…*understands but needs help occasionally-learn to take things apart, understands functionality in relation to design and can reassemble*." For material properties, the participants responded using language that primarily reflected the need for understanding with some experience. James (expert-level), "*Basic understanding of how those properties change when a manufacturing technology is applied to it*." Larry (expert-level) described it this way, "*proficient for the materials to be employed in the areas worked*." This knowledge is not needed just for the inherent knowledge of the material. For instance, when will a material fail when exposed to extreme cold or a vacuum? James discussed the importance of the ability to take knowledge and internalize it in a way that allows for comparison or substitution.

> *Understanding material properties is really important,... being able to look at a design and say, have you considered using this material instead of the material you're using? The current material you are using is incredibly expensive, this other material is not very expensive…. Working with, being able to, if I had a deeper understanding of metals and machining while I was a manufacturing engineer, I could have advised the design engineers better ways to make their parts so that they are assembled easier…. If you understood some of the additive methods, some of the other creative manufacturing processes out there oh, let's say coatings and coating applications and how those are done. The different ways to adhere metal to itself. A rudimentary understanding of those would help,*

would help you give you a leg up when it comes to, when you come to that manufacturing engineering role.

Additive manufacturing is a growing area where companies are looking for experienced employees. Companies are looking for employees who have the ability to understand and apply additive manufacturing in new areas. Julia (expert-level) discussed this need in her response.

There are emerging technologies that are of high interest to employers and they are all in aerospace looking for people with hands-on experience with friction stir welding, 3D printing or, I guess additive manufacturing. And additive manufacturing would be a very big one. I think employers are looking for engineers who have enough knowledge to understand the technology and enough creative thinking to understand where it can be applied.

MATLAB and LabVIEW are two software programs that are commonly used on commercial space manufacturing lines. Manufacturing engineers are expected to be able to operate the software, but not necessarily develop programs. When discussing programming abilities, Adam said the manufacturing engineer needs to "*understand, but needs help occasionally*." Zane (expert-level) described the level of skill as being "*being competent… because most of the data acquisition that's done during integration is through LabVIEW-enabled transducers, or thermocouples, or things like that*."

As part of the third core technical skills, evaluation and procedures of the manufacturing engineer, there are several subskills such as CAD, GD&T, and stress. Stress, according to Adam, is an area where the manufacturing engineer should be "*familiar with basic operational characteristics*." In the other topics, GD&T and CAD specifically, participants are more diverse in their descriptions.

For CAD skills, Larry felt the manufacturing engineer should have "*CAD skills as far as able to access information and examine the component models...*" He did not expect a manufacturing engineer to be familiar with all CAD programs, but "*if you know enough about all the tolerancing, that type of thing, and how to do those kinds of things on a CAD machine in general, those things should be transportable from system to system*." The manufacturing engineer does not need to create or draw anything in whatever CAD program that is being used according to Adam. This is an area where Adam feels there needs to be more experience.

> *They don't have to draw anything in there, it's a matter of just manipulating the model and understanding to use the calipers and the functions of modeling…. I'm seeing students are coming out of school that just don't have a lot of CAD experience and we want more of that. Things will transition quicker, oh yeah, this is a little bit different platform, but I can easily access the model.*

Unlike CAD, some stated the skill level needed for GD&T is more in-depth. James stated, "*I think you need to have a deep understanding of machining and GD&T.*" Adam echoed that sentiment; he stated that a manufacturing engineer should be able to "*understand and doesn't need help*". However, at a later time, he said employees should understand, but "*needs help occasionally*". Larry also said a manufacturing engineer should be "*proficient*" and be able to "*access information and examine the component models*." James also discussed how expert-level knowledge of GD&T is valuable to the manufacturing engineer.

> *I would much rather have a guy got a full almost expert-level GD&T. Cause if you are able to do that when you get out of school, you're going to be incredibly useful and be able to drop into any level of manufacturing. Because you can interpret, and if you can tell by looking at the drawing, well this sucks. Well, we*

can fix this, here's how we're going to fix this. If you give me this, I can make a new one over again easily.

For an entry-level manufacturing engineer, there are few areas where there is an expectation of true proficiency or expertise. The participants generally spoke to the level of understanding using terms like "understanding with some amount of help"; however, one place where proficiency could be expected according to the participants is in product evaluation. This is where GD&T, CAD, and drawing interpretation are located.

Theme 5. The Interpreter, or the bridge between the design engineer and the shop floor

The manufacturing engineer as the interpreter is based on comments from James (expert-level), Lisa (entry-level), and Ben (entry-level) and their discussion on how the manufacturing engineer is a "bridge" between other groups. While responses focused primarily on the communication between the design engineer and the shop floor technician, it was not limited to them. The manufacturing engineer interfaces with groups and individuals beyond the design engineer or technician.

Due to the differences in education, training, and job requirements it is difficult for true communication to occur between someone who works on the shop floor and design engineers. It is not uncommon to hear in the industry that technicians and design engineers speak different languages. When it comes to manufacturing, it is a system where engineers and technicians are focused on and care about different things. The shop floor worker is concerned about how to take the piece parts or processes to build whatever part or component that is in front of them. The design engineer is thinking, for instance, about how the material will react in the intended environment of the system. They wonder if all the parts they designed interact well with other parts in the system. Some of those other parts were designed by others.

The participants in this study identified three ways the manufacturing engineer is an interpreter: they need to be able to talk about the process in laymen's terms, manufacturing is a cooperative effort needing everyone to be communicating, and they are a bridge between the design engineer and the shop floor. When the participants discussed this theme, their reasoning was tied to the purpose of their jobs. One requirement of their job was to work with other people. Larry (expert-level) discussed this by highlighting the idea that two people can come up with more ideas than just one.

> *It's a cooperative effort. You have to know something to be able to interact and give the person you are interacting with feedback to say, oh okay what else do you need to know? Here's what I know. And we can put the two pieces together to put together something bigger than the two pieces alone.*

Manufacturing is not only about ideas, but also about how a production line is a fast-moving process with many moving parts managed by many different people with vastly different backgrounds and purposes. The manufacturing engineer is the hub through which all efforts are coordinated and they keep everyone informed of the progress. Ben discussed this part of the job, "*It's not just about you knowing, it's about everybody knowing where we are in the process*."

It would be much simpler if there was only one or two people or one or two different types of people to coordinate with; however, that is not the case. They not only have differences in education and training, but they may also speak different languages. With those constraints, sometimes the best way to communicate is not through words. Lisa discussed this phenomenon during her interview.

> *You have to be able to communicate with a variety of different people. You are on the floor with people who are building hardware and sometimes they don't all*

speak English. You have to be able to communicate both verbally and through drawings and you need to be able to communicate with those people.

James discussed this phenomenon during his interview, the focus not just on the receiving, but also the transmitting of information. He felt it was important not only to listen, but communicate in a way that felt familiar to the listener. It is important to reach out to the other person and exchange information where they are comfortable.

> *The way that [redacted] had it set up I interfaced with senior management. I interfaced with engineering, with chief engineers. I interfaced with basically everything that was involved with the production of that rocket. Not so much with the test folks, but there were times where you have to do system test, so I had to go and interface with those folks. So it was really important to know how they talked and how they communicated and try to communicate in a manner they expected.*

This theme is not just about communicating; it is about being the person among multiple others who is responsible for bridging the gap between them. Two of the most common types of people who were mentioned in the interviews were shop floor technicians and design engineers. Ben expressed it most succinctly, "*In my opinion, a manufacturing engineer is a bridge between the design engineer and the shop floor*". Therefore, you need to have an understanding of both those worlds because they can be quite different. But, Ben was not the only participant to discuss the interaction between the manufacturing engineer, their job, and how they interact with others. Adam (expert-level), James, Lisa, and Ben also highlighted the connection between the manufacturing engineer and others.

Adam: In the manufacturing engineer environment, that's what your job. (sic) The production is, they are coming to you, and they are saying we have a problem and you need to figure it out. You're the guy on site.

James: … if I had a deeper understanding of metals and machining while I was a manufacturing engineer, I could have advised the design engineers better.

Lisa: Most of the time drawing review boards if they're making a change to the drawings they have a review board and the review board is going to have a manufacturing engineer on it. They're going to have quality engineers in there and they're going to have electrical engineers, mechanical engineers, management people and you have to be able to communicate with anyone who's on a review board for drawing change request…. Having that level of understanding of hands-on experience. It also helps you relate so much better to other people on the production floor. Just that shared experience of actually having built things helps. It's just indispensable. Indispensable…. If it's a union shop, you're interacting with the union in a way that may be engineers or management isn't.

Ben: Here was another thing that I was thinking of... stress analysis. Stress I don't use as much, but I do think that is useful to know so you could understand the language where some of the stress people are coming from.

The job of a manufacturing engineer is complex and requires knowledge of various technical skills and competencies. This is not the only thing manufacturing engineers need to know; they also need to be able to communicate in a manner that is coherent, useful, and expressive. All the while, even if the basic information is the same, different approaches may be needed when the audience varies. The shop floor personnel will want a different perspective on the information than the design engineer or the manager may want or need.

Theme 6. The Storyteller, or make your data tell a story

The manufacturing engineer as a storyteller is based on comments from participants James (expert-level), Nick (entry-level), and Larry (expert-level). They viewed part of the job of a manufacturing engineer is to present data in a way that tells a story. This is because to influence and improve the manufacturing process, manufacturing engineers must find a way to gather and package data to reflect necessary changes by creating stories. These stories may be reflective of something extremely simple such as why and how to change the material type. It may also be more complex where the manufacturing engineer can influence the entire manufacturing process. Manufacturing engineers can advocate for more substantive changes such as rearranging or reordering testing procedures, including new testing procedures, or requesting the design engineers to complete a major redesign on a part because it will be significantly easier to manufacture.

Manufacturing engineers take disparate pieces of information and combine them into a cohesive narrative and with these data, create stories. Those stories are used to create compromises and influence decision making. James reflected on the need for negotiation and persuasion skills.

> *Negotiation is also important being able to understand and identify what is important to people. And being able to reach a compromise to get kind of what you want and what you need and what the rocket needs while also helping them, whomever [sic] you're interfacing with, feel good about whatever decision you made.*

Experienced manufacturing engineers have a lot of information coming at them, and entry-level manufacturing engineers not only have all that, but also have new ideas, skills, and concepts they are learning. One of the most difficult things a new manufacturing engineer has to do is understand what the data are telling them. During Nick's interview, he discusses the need for familiarity with the work, the current tasks, and how the manufacturing engineer fits into the narrative.

> *So, I think one of the biggest parts of it is having an awareness of your workspace and being able to understand exactly everything that's happening in the design. Whether it be your rocket, your capsule, or your jet plane. You have to know exactly why all of the processes happen the way they do in your formal area and then also why things happen the way they do… and where things don't need to be happening as well.*

This sentiment was echoed in Larry's interview. He discussed how important it was to create a narrative to understand the process flow. Larry felt it was central for manufacturing engineers to not only have the pieces of information, but also be able to translate them into useful information.

> *You have to know where and how to get this stuff [information]. And once you found it being able to put it in an overall framework…. Then balance that against what's in the change management process. Here's what the requirements are. Oh, now I understand why this looks like this. Oh, I'm supposed to do this with that, also. This [piece] doesn't meet that [piece]. And then start from there just being able to say here's the next step.*

The need to explain to others is the second take away from this theme. It is not uncommon for managers or design engineers to come to a manufacturing engineer and ask about the status of the hardware. Simply telling a manager that the next step in production is on hold waiting for the wiring harness to be completed is not likely as informative as management may want. They may not understand all of the tasks that are still required to complete assembly such as the status of the component parts or the status of harnesses scheduled to be completed prior to their wire harness. Manufacturing has many moving parts and it is the manufacturing engineer's job to ensure that everybody knows what is happening. When this does not happen, Ben (entry-level) called it "*the right hand not talking with the left hand*".

Manufacturing is a highly complex process that involves many different people. Not one person is responsible for everything so understanding where your piece fits in with the others is necessary. Coordination must happen with others to have that big picture. Nick discussed this challenge, "*So, it's difficult to understand all of the individual processes that happen, but [still] to be able to have a good big picture view of the manufacturing of a part or an aircraft...*"

These are merely building blocks for the true challenge which is to understand, articulate, and share the pertinent information that is important to a manufacturing engineer. That challenge is to compile all that information in such a manner as to create a narrative that influences other people. The development of the repairs or changes to current procedures are spearheaded by the manufacturing engineer. As Nick described.

> *But being able to make your data tell a story, and then having that story that you're able to tell, change people's opinions and in turn, change the culture of different things within the company, and actually, causes real results and impacts. I think that's a really important thing.*

Manufacturing engineers must go beyond simply knowing the information. They must in fact truly understand it. They must be able to share and explain it. They must be able to build an argument that is persuasive to a diverse audience. This goes beyond simple acclimation or competence. Manufacturing engineers must be experts in their jobs. It is an oversimplification to say that manufacturing engineers must be proficient analyzing data. They should, but analyzing data is merely one step towards the larger goal of influencing and improving the manufacturing process.

CHAPTER 5. CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

The purpose of this study was to explore the training, educational experiences, and technical competencies of entry-level manufacturing engineers in the commercial space industry. The research questions posited to achieve the objectives of the study included: (1) What are the training and education experiences of entry-level manufacturing engineers? (2) What are the technical competencies required for entry-level employment as a manufacturing engineer in a commercial space manufacturing company as described by entry-level and expert-level manufacturing engineers? (3) How do entry-level and expert-level manufacturing engineers describe the importance of these technical competencies? and (4) What level of knowledge of the technical competencies should the employee possess as described by expert-level manufacturing engineers?

Conclusions

Higher learning institutions are attempting to respond to the demand for an increase in aerospace technicians that include manufacturing engineers. However, industry needs are not easily understood, and higher education is tasked to satisfy industry demands with existing infrastructure and curriculum. To meet that need, universities and colleges require better information related to the technical skills and competency requirements. Additional studies that explore the educational experiences and training needs of manufacturing engineers are necessary to develop more focused and efficient curriculum and training programs. This study responded to this gap by exploring the educational experiences of entry-level manufacturing engineers, and the perceptions of expert-level manufacturing engineers pertaining to the skills and competencies that are required for entry-level manufacturing engineers.

The analysis of the data collected for research question one indicated that all the entry-level manufacturing engineer participants shared a common experience in the lack of formalized training after graduation. Company-sponsored training was fairly common in the aviation industry, but according to the experiences of the entry-level manufacturing engineers, job-specific technical training was limited or sometimes non-existent. A bachelor's degree from a college or university was not expected to alone provide an education that adequately prepares prospective manufacturing engineers to succeed in their careers. The college or university experience was limited in time and resources. They were unable to prepare students for all situations and possible challenges the student may confront at work. Preparing for all situations becomes even more untenable when all the variables between company-specific procedures and processes are taken into consideration.

Without the proper training, employees may not feel they are prepared adequately to be a successful manufacturing engineer. Effective mentors are connected to the training and influential to the success of the manufacturing engineer in at least two ways. The mentors are necessary for the dissemination of technical knowledge not previously obtained in a more formal training environment. Secondly, mentors provide the manufacturing engineer direction to obtain further information. The process, however, is not formalized, and subject to inconsistencies between manufacturing engineers and their training experiences.

The data collected for research question two revealed that the technical skills and competencies that are required for a manufacturing engineer to be successful can be grouped into three major categories: (a) mechanical, (b) software, and (c) evaluation and procedures. These are the technical competencies and skills that both expert-level and entry-level manufacturing engineers feel are important to possess for success as a manufacturing engineer. Some of the skills are more mechanical in nature including the ability to handle tools, understand the materials used in a system, or familiarization with advanced manufacturing techniques such as additive manufacturing.

Other skills are related to the ability to use software. MATLAB and LabVIEW are two software programs that were specifically noted by the participants. These programs are used to create and manage models used to build and test parts and systems. Familiarization with CAD programs is necessary for using the model in configuration management tasks. Participants did not specify a particular program, but only that manufacturing engineers be able to perform minor manipulation and interpretation of the model. The participants felt that CAD systems were common enough that the skill should be transferable between programs.

Although the participants mentioned many skills and competencies, the fact they can be grouped into three categories provides academia some structure and direction for curriculum adjustments. University programs may choose to view the categories for inspiration in spite of the fact they may not address all of the possibilities. Considering most academic programs are resource-restricted, the ability to focus on a few key areas for direction is useful in determining a path forward.

Research question three asked the participants to discuss the importance of the competencies. This is most closely related to the interview question regarding the consequences of making mistakes or bad decisions. Participants were asked to discuss why the skills were important and what happens when those skills were not satisfactory. The responses centered on the individual, the company, and the public at large. The participants reported on the possibility of a damaged reputation. When it was related to the company, responses included impact on cost and schedule. Broken or incorrectly manufactured components would require either new parts or repairs to existing parts. Repairs take time; repair time is not normally included in the schedule.

While additional costs and delayed schedules were not desirable results, they did not compare to the possible loss of life that could result. This was the consequence to the public at large. The participants were able to draw logical connections between simple mistakes and the death of civilians. These mistakes could be the mis-installation of a bolt or an improperly grounded circuit card. Taken by themselves, it was difficult to imagine how simple mistakes could result in death, but they could. Manufacturing engineers must be able to envision how their part connects to the whole and how their actions directly influence the ability for the final system to work correctly.

Research question four asked the expert-level manufacturing engineers to reflect on the level of knowledge the entry-level manufacturing engineer should have to be successful at their jobs. The results from this question were structured around the three categories that were identified: (a) mechanical, (b) software, and (c) evaluation and procedures. Mechanical skills were discussed by the participants using terms such as: (a) understands, but needs help occasionally, (b) enough for creative thinking, (c) basic understanding, (d) understand, (e) rudimentary understanding, and (f) proficient. Except for "proficient" and "enough for creative thinking" all the terms could reach the competence level of domain learning (Alexander, 2003). At the competence level, learners are able to accomplish some basic tasks unsupervised. In some areas, simple acclimation may be satisfactory. Based on the terms the participants used, this area is most likely to be the lowest level of knowledge in the three categories.

The category in the middle is software. The participants used terms like “competent” and “understand”. These terms place software knowledge in the competence level (Alexander, 2003). Manufacturing engineers use MATLAB and LabVIEW frequently, and the use of them is a requirement of the job. If the manufacturing engineer is in the competence level, they are able to work on more advanced tasks. Considering the frequency and variety of tasks the manufacturing engineer does, competence is a requirement.

The final category is the one where participants used terms reaching competence and sometimes beyond to proficiency. The participants used terms, such as, understands and doesn’t need help; deep understanding; familiar; full, almost expert; proficient; needs help occasionally; familiar; and know enough. The almost expert-level of proficiency for GD&T was mentioned by more than one participant. This area was clearly important to the expert-level manufacturing engineers and used language most related to the proficient level of knowledge (Alexander, 2003). CAD programs were less important; participants discussed the level of knowledge needed in competence terms such as familiar and know enough.

Implications

The purpose of a qualitative study is not generalizability. Though partial generalizations for similar populations may be possible (Myers, 2000). So while broad generalizations are not intended for this study, there are implications for three groups: (a) individuals who were currently or who desire to become manufacturing engineers, (b) commercial space manufacturing companies, and (c) academia. For the student desiring to become a manufacturing engineer, understanding what was required of them implies a better visualization of their future. Would knowing their future training be self-directed influence their academic pursuits? Students could focus their academic career on learning more about the availability of information and resources. Students should also understand that much of their learning is dependent on others, such as mentors. The use of mentors can be comforting for some, but others may be uncomfortable with the idea that they will be working so closely with someone who is, at least informally, responsible for their success.

There are implications for commercial space manufacturing companies as well. There is a benefit for those who hire employees at commercial space companies to understand the competencies required to be successful manufacturing engineers. For instance, companies can better focus their job searches on candidates who have competencies in the interpretation of engineering data or knowledge of the manufacturing process flow. By focusing on those competencies, rather than other areas, they can identify candidates who will contribute to the successful manufacturing of components or systems. Sometimes companies are focused on a particular degree which may or may not have the requisite competencies, but have the right name. Once companies are aware of the technical competencies that actually contribute to the success of the manufacturing engineer, they can focus on those that will matter once the candidate starts the job.

The commercial space industry has the opportunity to make significant changes in how they interface with academia or other training programs. By better understanding the competencies that are needed, the commercial space industry could reach out to individual colleges or universities to influence programs that already align somewhat with the required competencies. Many program personnel may perceive there are graduates who could be a good fit for manufacturing engineering positions, but do not have sufficient alignment. Industry would have the opportunity to communicate the competencies they require. This could result in training programs being established related to the technical competencies that are required.

There are also implications for colleges and universities. Programs that prepare students to be manufacturing engineers are linked to the needs of industry; sometimes colleges and universities have industrial review boards that assist them to better understand the needs of the industry. This study was intended to complement the recommendations of review boards. The combination of skills and depth identified in this study are areas that colleges can focus on in their programs. However, in addition to the technical skills, colleges and universities should focus on providing structure, opportunities, and encouragement for students to find their own resources. Answers and solutions in the manufacturing arena are not always readily available. It is necessary for the manufacturing engineer to become their own best resource to overcome this challenge.

Recommendations

This study, like most studies, had several limitations. First, the population was limited to eight participants who worked at six different commercial space manufacturing companies. It would be beneficial for the study to have included a larger number of participants and more companies. The operational definition of a commercial space company was very broad. Future studies could use an operational definition of commercial space that excludes companies that primarily and closely work for federal government agencies. The semi-structured format of the interview allowed participants to focus on areas that were important to them, but it also allowed less in-depth discussion in other areas. These were considered practical constraints and did not necessarily impede the study's findings, conclusions, and limitations. Accordingly, several recommendations are offered for policy, practice, and future research:

1. The number of participants and companies was small; future studies should use larger numbers of participants and companies.

2. Faculty should evaluate their programs for alignment with the competencies; degree programs should be adjusted to incorporate the competencies.
3. Commercial space manufacturing companies should develop formalized mentorship programs that include training for mentors.
4. Faculty should provide extra experiential opportunities for students in the required competencies; these opportunities would not be part of their degree, but an extracurricular activity that could be used to demonstrate competence to employers.
5. Industry and/or academia could develop short programs to be taken by individuals who have some experience and wish to be manufacturing engineers; these programs would not replace academic programs, but provide transitional training.
6. Persons desiring to become an entry-level manufacturing engineer should seek opportunities outside academia or existing job positions to improve their competency level; many of the competencies can be accomplished and documented in their personal life or activities.
7. Partnerships should be established between industry and academia to create programs that focus on the competencies.
8. Companies could search beyond the traditional degree programs and backgrounds for qualified manufacturing engineers. Traditionally, many companies want to place engineers in these positions; however, programs such as engineering technology programs are strong in the required competencies.

9. Future research could include a study with hiring managers or supervisors as participants; a different perspective might identify additional competencies or reveal other ideas regarding the depth of knowledge required for the technical competencies,
10. Future research should consider a study that focuses on non-technical competencies; technical competencies are not solely required for job success.
11. Future studies could be more quantitative in nature and connect with a larger population; with the current study as a foundation, an instrument could be developed, validated, and administered to a larger and more diverse population.
12. Future research should examine the competencies and skills required for experienced manufacturing engineers; the evolution from entry-level to experienced manufacturing engineer may reveal new areas that could be incorporated into programs.

In summary, it is important for both industry and academia to become aware of the educational experiences and technical competencies required to become a successful manufacturing engineer. They should seek opportunities for individuals to increase their knowledge with respect to the required competencies. These could be programs more closely aligned with industry or individual company needs. Individuals could also seek opportunities in their personal lives and practice these competencies to enhance their skills. Companies, individuals, and academia can work together to better identify and provide opportunities to enhance technical competencies. An increase in skills similarly increases the manufacturing engineer’s satisfaction with their job and success.

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APPENDIX A. NASA EMPLOYEE COMPETENCIES

Competency	**Frequency**
Management	2078
Financial Operations	1564
Business Operations	1439
Administrative Operations	1243
Program/Project Management	1080
Engineering and Science Support	976
Institutional Operations and Support	660
Systems Engineering	572
Mission Execution	490
Program/Project Analysis	331
Workforce Operations	298
Software Engineering	297
Quality Engineering and Assurance	230
Network Systems and Technology	224
Materials Science and Engineering	209
Electrical and Electronic Systems	201
Flight and Ground Data Systems	194
Test Engineering	187
Mechanical Systems	181
Safety Engineering and Assurance	180
Advanced Missions/Systems Concepts	151
Control Systems, Guidance and Navigation	146
Computer Systems and Engineering	141
Mission Analysis, Planning, and Design	129
Power Systems	127
Advanced Experimentation and Testing Technologies	125
Earth Atmosphere	123
Propulsion Systems and Testing	120
Aerodynamics	113
Rocket Propulsion	109
Thermal Systems	108
Technical Management	108
Astronomy and Astrophysics	106
Mathematical Modeling and Analysis	104
Mission Assurance	93
Intelligent/Adaptive Systems	78
Avionics	77
Simulation/Flight Research Systems	74
Optical Systems	74
Space Physics	74

Competency	Frequency
Remote Sensing Technologies	71
Advanced Measurement, Diagnostics, and Instrumentation	71
Extravehicular Activity Systems	68
Planetary Science	67
Crew Systems and Aviation Operations	64
Structural Dynamics	64
Fluid Physics Systems	60
Human Factors Research and Engineering	59
Electromagnetics	57
Acoustics	51
Electro-Mechanical Systems	49
Cryogenics Engineering	49
Sensors and Data Acquisition—Aeronautics	48
Advanced Analysis and Design Method Development	48
Advanced Technical Training Design	48
Robotics	44
Environmental Control and Life Support Systems	42
Biomedical Research and Engineering	39
Aerothermodynamics	38
Chemistry/Chemical Engineering	37
Non-destructive Evaluation Sciences	37
Reliability and Maintainability Engineering and Assurance	37
Earth Science Applications Research	37
Air Traffic Systems	36
Analytical and Computational Structural Methods	36
Integrated Logistics Support	31
Airbreathing Propulsion	30
Mechanics and Durability	30
Combustion Science	29
Process Engineering	26
Aerospace Medicine	26
Habitability and Environmental Factors	25
Advanced In-Space Propulsion	25
Space Environments Science and Engineering	22
Astrobiology	22
Fundamental Physics	21
Data Systems and Technology	20
Laser Technology	20
Electron Device Technology	19
Software Assurance Engineering	19
Aeroelasticity	18
Earth System Modeling	18
Configuration Management	17
Flight Dynamics	16

Competency	Frequency
Thermal Structures	15
Risk Management	15
Biology and Biogeochemistry of Ecosystems	15
Microwave Systems	14
Biology	14
Micro-Electromechanical Systems	13
Nanoscience and Technology	13
Payload Integration	12
Oceanographic Science	12
Pyrotechnics	10
Geophysical/Geologic Science	10
Geospatial Science and Technologies	10
Icing Physics	9
Bioengineering	8
Terrestrial and Planetary Environmental Science/Engineering	8
Hydrological Science	8
Imaging Analysis	6
Weather Observation and Forecasting	6
Astromaterials, Collections, Curation, and Analysis	5
Climate Change and Variability	4
Neural Networks and Systems	3
Hypergolic Systems	3
Nuclear Engineering/Propulsion	3
Planetary Atmospheres	1
Bioethics	1
Metrology and Calibration Competency	0

Reprinted from *Building a better NASA workforce: Meeting the workforce needs for the national Vision for Space Exploration,* by the National Research Council. Committee on Meeting the Workforce Needs for the National Vision for Space Exploration, retrieved from https://ebookcentral.proquest.com/lib/purdue/reader.action?docID=3564118&query=

APPENDIX B. SPACETEC CORE CERTIFICATION COMPETENCIES

Introduction to Aerospace
- Regulations and Controls
- Clean Room, Contamination and FOD
- Ethics
- Quality Assurance and Quality Control

Aerospace Safety
- Toxic and Hazardous Substances
- Personal Protection Equipment
- Hazardous Materials
- Emergency Plans and Fire Prevention
- Platforms
- Occupational Health and Environment
- Walking Surfaces

Applied Mechanics
- Machine Shop Safety
- Non-Cutting Hand Tools
- Cutting Hand Tools
- Drill Presses, Twist Drills, Drilling Speeds and Feeds, Drilling Holes
- Basic Measurement
- Basic Calculations (Metric to Standard, Ratios, Volume, Area, Dimensions)
- Micrometers
- Calipers
- Hardware and Materials Identification
- Blueprint Reading and Interpretation
- Interpret Technical Drawings and Schematics

Basic Electricity
- Electric
- Safety
- Metric Notation
- Atomic Structure
- Resistors
- Switches
- Schematic Reading
- AC/DC Circuits
- Theory
- Laws

Materials and Processes I & II

- Metallurgy
- Metallurgical Processes
- Mechanical Behavior
- Conventional Mechanical Testing
- Corrosion
- Corrosion Forms, Causes, Prevention
- Corrosion Control
- Non-Metallic Materials
- Structural Characteristics
- Solid Core Structures, Molds, Moldless Wet Lay-up Techniques
- Hollow Structures and Mold Making
- Vacuum Bagging

Test and Measurements

- Inspection Requirements and Planning
- Accuracy, Precision and Tolerances
- Mechanical Measuring Inspection
- Mechanical Surface Plate Inspection
- Electrical /Electronic Measurements
- Electrical Pressure/Flow/Temperature Measurement
- Force/Strain/Torque/Vibration Measurement
- Non-Destructive Examination
- Surface Flaw Inspection
- Delamination Inspection
- Electromagnetic Techniques
- Radiographic Techniques

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APPENDIX C. UNITED STATES COMMERCIAL SPACE COMPANIES WITH EMPLOYMENT NUMBERS

Organization Name	Employment Number	Reference for Employee Number	Company Description
Accurate Automation Corp.	12	https://www.sbir.gov/sbc/accurate-automation-corporation	Manufacture UAV; unmanned surface vehicles; transient voltage suppression technologies & guided missiles
Ad Astra Rocket Co.	15	http://www.adastrarocket.com/aarc/team	Dev. advanced plasma rocket propulsion systems, including the variable specific impulse magnetoplasma rocket
Aerojet Rocketdyne	5,157	2017 Annual Report https://ir.aerojetrocketdyne.com/static-files/c9ad6d93-a4c1-4f80-bacb-03c6d443adac	Develop & manufacture solid & liquid propulsion systems for aerospace; precision tactical weapon systems; & armament systems, including warhead & munitions applications
Alaska Aerospace Corp.	n/a		Aerospace launch services
Ball Aerospace & Technologies Corp.	18,300	2017 Annual Report - Includes food and beverage	Manufacture satellites & spacecraft, space/ground systems, electro-optics sensors, electromech. devices, stored cryogen systems, communication systems & tech. services
Blue Origin, LLC	1,500	https://www.reuters.com/article/us-space-blueorigin/bezos-throws-cash-engineers-at-rocket-program-as-space-race-accelerates-idUSKBN1KO0HN	Design, develop & manufacture spacecraft, rocket engines & reusable launch vehicles

Organization Name	Employment Number	Reference for Employee Number	Company Description
Boeing Network & Space Systems	2,732	van der Bijl, 2017	Manufacture space systems, satellites & payloads for national defense, science & environmental applications
Comtech AeroAstro, Inc.	1,109	2018 Annual report http://www.comtechtel.com/static-files/05513f16-a5de-4ee6-bc37-fe907c485ddd	Design & manufacture micro & nanosatellites; sun sensors & components; orbital transfer services; spacecraft mission consulting; spacecraft communications
Constellation Services International, Inc.	10	https://www.linkedin.com/company/constellation-services-international-inc-/about/	Entrepreneurial orbital services focused on research & applications logistics for low earth orbit (LEO) space stations
Deep Space Industries	50	https://www.linkedin.com/company/deep-space-industries/about/	Design, develop & manufacture spacecraft & propulsion systems for deep space exploration, including the Explorer spacecraft & Comet water-based satellite propulsion system
Frontier Astronautics, LLC	10	http://www.frontierastronautics.com/about-frontier-astronautics.php	Design, develop & manufacture rocket engines & attitude control systems; custom design & testing of customer rocket engines & flight vehicles
IHI Turbo America Co.	n/a		Design & Manufacture turbo charges and super charges for marine and automotive applications
IHI, Inc.	6,348	Integrated Annual Report https://www.ihi.co.jp/i/pdf/integrated2017_all_en.pdf	Manufacture jet engines, industrial gas turbines, heavy machinery & equipment & various kinds of processing plants; Dev. & manufacture turbo pumps for H-IIA rockets; dev. GX rocket systems

Organization Name	Employment Number	Reference for Employee Number	Company Description
Kistler Space Systems, formally Kistler Aerospace Corp.	unknown		#N/A
L3 Electron Technologies, Inc.	31,000	Annual report https://www.l3t.com/sites/default/files/annual-reports/2017_l3_annual_report_0.pdf	Design & manufacture electronic products, including microwave tubes & microwave tube amplifiers for satellites, aircraft & telecommunications; next-generation xenon ion propulsion (XIPS) systems for satellite station-keeping
Lockheed Martin Space Systems Co.	16,000	Lockheed Martin to slash 1,200 jobs at Space Systems Unit http://www.rttnews.com/story.aspx?Id=1646041	Design & manufacture human space flight systems; full range remote sensing, navigation, meteorological & communications satellites & instruments; space observatories & interplanetary spacecraft; laser radar; fleet ballistic missiles; missile defense systems
Lockheed Martin Space Systems Co. - Michoud Operations	n/a		Design & manufacture human space flight systems; remote sensing; navigation, meteorological & communications satellites & instruments; space observatories & interplanetary spacecraft
MDA Information Systems, Inc. - Space Div.	4,800	Annual Report http://www.annualreports.com/HostedData/AnnualReports/PDF/TSX_MDA_2016.pdf	Manufacture custom products, space applications; space programs support; composite structures, robotics, mechanisms & mech. analysis

Organization Name	Employment Number	Reference for Employee Number	Company Description
Masten Space Systems	8	Wikipedia https://en.wikipedia.org/wiki/Masten_Space_Systems	Design, develop & manufacture reusable vertical-takeoff, vertical landing (VTVL) rockets for commercial customers & government agencies; lunar vehicles & rocket engines
Northrop Grumman Innovation Systems, formally Orbital ATK Flight Systems Group	12,500	Annual Report http://www.annualreports.com/HostedData/AnnualReportArchive/o/NYSE_OA_2016.pdf	#N/A
Orbital ATK Inc.	Purchase by Northrop Grumman		Design, manufacture, operate & mkt. space transportation systems, spacecraft systems, & payloads; space support products; satellite-based mobile communications, earth observation & space research services
Orbital ATK Space Systems Group	Purchase by Northrop Grumman		Design, dev. & manufacture commercial & military satellites & space system components
SNC Space Systems California	4,500	Wikipedia https://en.wikipedia.org/wiki/Sierra_Nevada_Corporation	Offers turn-key space missions from earth-orbit to deep-space
Scaled Composites, LLC	200	Wikipedia https://en.wikipedia.org/wiki/Scaled_Composites	Air vehicle design, tooling & manufacturing; specialty composite structure design, analysis & fabrication; developmental flight tests

Organization Name	Employment Number	Reference for Employee Number	Company Description
Space Systems/Loral, LLC.	2,900	Wikipedia https://en.wikipedia.org/wiki/SSL_(company)	Design & manufacture communication satellites & satellite systems; broadband digital communications, wireless technology; environmental monitoring
SpaceX	7,000	Jeff Foust tweet https://twitter.com/jeff_foust/status/931087032830582784	Design, manufacture & launch advanced rockets & spacecraft
Stanford Mu Corp., Space Components Div.	16	https://craft.co/stanford-mu-corporation	Design, dev & manufacture high precision fluid control components for spacecraft & launch vehicles
The Spaceship Company	430	The Spaceship Company "Who We Are" http://thespaceshipcompany.com/who-we-are/	Manufacture reusable spacecraft & launching aircraft, including the SpaceShipTwo spacecraft & the WhiteKnightTwo carrier aircraft
United Launch Alliance, LLC	3,400	https://www.owler.com/company/ulalaunch	Manufacture & provides engineering, test & launch operations
Ventions, LLC	10	LinkedIn https://www.linkedin.com/company/ventions-llc/about/ SBIR by Small Business Association https://www.sbir.gov/sbc/ventions-llc	Design, fabrication & testing of aerospace hardware components for launch vehicles & space propulsion systems; avionics & flight computers for vehicle auto-sequence, gimbal control, GNC, telemetry & vehicle power management

Organization Name	Employment Number	Reference for Employee Number	Company Description
XCOR Aerospace, Inc.	closed	Wikipedia https://en.wikipedia.org/wiki/XCOR_Aerospace	Dev. rocket-propelled vehicles, rocket propulsion systems, & propulsion components
Total Employees	**118,007**		

APPENDIX D. INFORMATION FORM: ENTRY-LEVEL

RESEARCH PARTICIPANT INFORMATION SHEET

Expectations of commercial space industry professionals toward technically qualified individuals for entry-level manufacturing support engineer positions

Tracy L. Yother, Co-Investigator and Dr. James Greenan, Principal Investigator

Curriculum and Instruction

Purdue University

Key Information

Please take time to review this information carefully. This is a research study. Your participation in this study is voluntary which means that you may choose not to participate at any time without penalty or loss of benefits to which you are otherwise entitled. You may ask questions to the researchers about the study whenever you would like. If you decide to take part in the study, you will be asked to sign this form, be sure you understand what you will do and any possible risks or benefits.

The purpose of this study is to explore the expectations of industry professionals at commercial space companies toward the technical competencies required of entry-level manufacturing support engineers. What should they know? How much depth in those competencies is required? How critical is it for them to know? For this part of the study we are investigating the education and training experiences of entry-level manufacturing engineers in the commercial space industry.

The time commitment for this study overall is approximately one hour.

You are being asked to participate because of your experience as a manufacturing engineer, or other related job titles, in the commercial space industry. We would like to enroll seven people in this study.

What will I do if I choose to be in this study?

This exploratory study will interview four expert-level and three entry-level manufacturing engineers. If you participate in this study, an interview will be scheduled that should last between 1 and 1 ½ hours. Once the interviews are complete, a transcription service will be used to transcribe the data. After the transcription is complete it will be sent to you for final review and approval.

How long will I be in this study?

The time commitment for this study is the interview time of 1 to 1 ½ hours and time to review the transcription.

What are the possible risks or discomforts?

Risks in this study are no greater than you would encounter in daily life. Breach of confidentiality is always a risk with data, but we will take precautions to minimize this risk as described in the confidentiality section.
Breach of confidentiality is always a risk with data, but we will take precautions to minimize this risk as described in the confidentiality section.

Are there any potential benefits?

The benefit of this study is general knowledge to improve the educational practices of the manufacturing support engineer function in the commercial space industry.

Will information about me and my participation be kept confidential?

Data will be held confidential. Interviews will be transcribed using an IRB approved transcription service Once transcriptions are complete identifying information will be removed and original audio recordings will be deleted. All data will be stored on a secured data server managed by Purdue University. Transcriptions will be maintained for three years.

What are my rights if I take part in this study?

You do not have to participate in this research project. If you agree to participate, you may withdraw your participation at any time without penalty.
To withdraw from the study at any time send an email to either the principle investigator, Dr. James Greenan, jgreenan@purdue.edu, or key investigator, Tracy Yother, tyother@purdue.edu. You may also contact the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) with any questions, concerns, or to withdraw from the study.

APPENDIX E. INFORMATION FORM: EXPERT-LEVEL

RESEARCH PARTICIPANT INFORMATION SHEET

Expectations of commercial space industry professionals toward technically qualified individuals for entry-level manufacturing support engineer positions

Tracy L. Yother, Co-Investigator and Dr. James Greenan, Principal Investigator

Curriculum and Instruction

Purdue University

What is the purpose of this study?

The purpose of this study is to explore the expectations of industry professionals at commercial space companies toward the technical competencies required of entry-level manufacturing support engineers. What should they know? How much depth in those competencies is required? How critical is it for them to know? Is the term or concept important because it is frequently used, or is it critical because a misunderstanding implies a loss of valuable equipment or even more critically, the loss of life?

What will I do if I choose to be in this study?

The procedures for this study will begin with a pilot study with one participant. Data collected from the pilot study will not be used as part of the study, but instead to assist in identifying the relevant lines of questioning. Once the pilot study is complete, study participants will be contacted to schedule the first interview. A follow-up interview will be scheduled at the end of the first interview. The follow-up interview is to clarify any lingering issues or provide clarification from the first interview. The time commitment for this study overall is approximately one hour. There are two interviews that should take approximately 30 minutes each. Interviews will take place within a two week.

What are the possible risks or discomforts?

Risks in this study are no greater than you would encounter in daily life. Breach of confidentiality is always a risk with data, but we will take precautions to minimize this risk as described in the confidentiality section.

Are there any potential benefits?

The benefit of this study is general knowledge to improve the educational practices and hiring requirements of the manufacturing support engineer function in the commercial space industry.

Will information about me and my participation be kept confidential?

Data will be held confidential. Only the principle investigator, Dr. James Greenan, and co-investigator, Tracy Yother, will have access to the original audio recordings. Interviews will be transcribed and all identifying information will be removed during the transcription process. Once transcriptions are complete original audio recordings will be deleted. All data will be stored on a secured data server managed by Purdue University. Transcriptions will be maintained for three years.

What are my rights if I take part in this study?

You do not have to participate in this research project. If you agree to participate, you may withdraw your participation at any time without penalty.

To withdraw from the study at any time send an email to either the principle investigator, Dr. James Greenan, jgreenan@purdue.edu, or key investigator, Tracy Yother, tyother@purdue.edu. You may also contact the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) with any questions, concerns, or to withdraw from the study.

APPENDIX F. INTERVIEW PROTOCOL: EXPERT-LEVEL (PILOT STUDY)

Interview Guide

Press Record…

Good morning/afternoon/evening. My name is Tracy Yother, and I am a PhD student in education from Purdue University. Thank you for your time today. If it is okay with you I will be recording our conversation.

Wait for response.

Before we get started I wanted to take just a moment to let you know what is going to happen over the next half hour.

I have nine questions. The first four questions are simply information gathering about you and your background. The remaining five questions are about the typical skills or competencies required for an MSE, how in-depth they should know or be able to perform those skills or competencies, and the consequences of not knowing those skills are competencies. The interview is semi-structured so feel free to ask any questions or clarification that comes up.

For the interview I will be asking your name, however, once the transcription is made I will be anonymizing your information and then deleting the audio file. This will ensure anything you tell me will be kept confidential, meaning that only I will be aware of your answers.

I am here to learn about the competencies required for entry-level manufacturing support engineers. There are no right or wrong answers so please feel free to answer in whatever manner makes you comfortable.

I have provided you an information sheet that reviews your rights during this study. Do you have any questions about them or the study procedures?

Wait for response.

Okay, let's get started.

1. What is your name?
2. What is your current job/position?
3. How long have you worked in the commercial space industry?

4. How long have you worked as a manufacturing support engineer?
5. What is a typical day for a new manufacturing support engineer?
6. From your perspective, what are the important technical skills that an entry-level level manufacturing support engineer?
    1. *Follow-up questions could be focused on exploring technical skills.*
    2. *May require refocusing only on technical competencies.*
7. From your perspective, is it important that the entry-level MSE be more than just familiar with any of the skills, or is knowing the concept enough?
    1. *Follow-up questions could be focused on discussing a specific skill and how knowledgeable they should be with that skill.*
8. Why are these skills important?
9. What is an example of the possible consequences of a mistake happening because the MSE did not have the required competencies?

Thank you again for your time. I was hoping that before we end the interview we could schedule a time to discuss any questions that may come up or answer any follow-up questions?

APPENDIX G. INTERVIEW PROTOCOL: EXPERT-LEVEL

Interview Guide

Press Record…

Good morning/afternoon/evening. My name is Tracy Yother, and I am a PhD student in education from Purdue University. Thank you for your time today. If it is okay with you, I will be recording our conversation.

Wait for response.

Before we get started, I wanted to take just a moment to let you know what is going to happen over the next half hour.

I have six questions. The first four questions are simply information gathering about you and your background. The remaining three questions are about the typical skills or competencies required for an MSE, how in-depth they should know or be able to perform those skills or competencies, and the consequences of not knowing those skills are competencies. The interview is semi-structured so feel free to ask any questions or clarification that comes up.

For the interview I will be asking your name, however, once the transcription is made, I will be anonymizing your information and then deleting the audio file. This will ensure anything you tell me will be kept confidential, meaning that only I will be aware of your answers.

I am here to learn about the competencies required for entry-level manufacturing support engineers. There are no right or wrong answers so please feel free to answer in whatever manner makes you comfortable.

I have provided you an information sheet that reviews your rights during this study. Do you have any questions about them or the study procedures?

Wait for response.

Okay, let's get started.

1. What is your name?

2. Can you give me a short description of the jobs and companies you have worked for including?
    1. What is your current job/position?
    2. How long have you worked in the commercial space industry?
    3. How long have you worked as a manufacturing support engineer?
3. What is a typical day for a new manufacturing support engineer?
4. From your perspective, what are the important technical skills that an entry-level level manufacturing support engineer?
    1. *Follow-up questions could be focused on exploring technical skills.*
    2. *May require refocusing only on technical competencies.*
5. From your perspective, is it important that the entry-level MSE be more than just familiar with any of the skills, or is knowing the concept enough?
    1. *Follow-up questions could be focused on discussing a specific skill and how knowledgeable they should be with that skill.*
6. Why are these skills important to the MSE, the company, or both?
7. What is an example of the possible consequences to the MSE, the company, or both, of a mistake happening because the MSE did not have the required competencies?
8. Is there a difference in technical skills between space and aviation?

Thank you again for your time. I was hoping that before we end the interview, we could schedule a time to discuss any questions that may come up or answer any follow-up questions?

APPENDIX H. INTERVIEW PROTOCOL: ENTRY-LEVEL

Interview Guide

Press Record…

Good morning/afternoon/evening. My name is Tracy Yother, and I am a PhD student in education from Purdue University. Thank you for your time today. If it is okay with you, I will be recording our conversation.

Wait for response.

Before we get started, I wanted to take just a moment to let you know what is going to happen over the next half hour.

I have a few questions. The first set of questions are simply information gathering about you and your background. The remaining questions are about your education and training experiences and the typical skills or competencies required for an MSE, how in-depth they should know or be able to perform those skills or competencies, and the consequences of not knowing those skills are competencies. The interview is semi-structured so feel free to ask any questions or clarification that comes up.

For the interview I will be asking your name, however, once the transcription is complete, I will be anonymizing your information and then deleting the audio file. I will be using a transcription service that is approved through IRB for the interviews.

I am here to learn about your experiences in formalized education and training. There are no right or wrong answers so please feel free to answer in whatever manner makes you comfortable.

I have provided you an information sheet that reviews your rights during this study. Do you have any questions about them or the study procedures?

Wait for response.

Okay, let's get started.

1. What is your name?

2. Please give me a short description of the jobs and companies you have worked for.

   1. What is your current job/position?
   2. How long have you worked in the commercial space industry?
   3. How long have you worked as a manufacturing engineer?

3. From your perspective, what are the important technical skills that an entry-level level manufacturing engineer should have?

4. What type of education or training did you receive prior to taking your position as a manufacturing engineer?

5. What is an example of where your education or training help you face and overcome technical challenges in your job?

6. What is an example of where your education or training did not help you in a technical area?

7. Please describe the types and topics of training or education that have been the most beneficial to you?

8. What are some of the types and topics in which you felt most unprepared for in your position due to education or training?

9. What are the challenges that you face in obtaining further education or training?

10. What are some areas in education or training that could be improved?

Thank you again for your time.

APPENDIX I. CODES AND THEIR RELATIONSHIP TO THE THEMES

Theme 1. Mentoring used as a teaching tool

- lack of information
- knowledge transfer
- the guy sitting next to you

Theme 2. You're going to be doing pretty good

- mechanical
    - materials
    - tools
    - additive manufacturing
- software
    - Matlab
    - LabVIEW
- evaluation and procedures
    - evaluate
        - CAD/GD&T/drawing interpretation
    - clean room

Theme 3. Worst case is millions of lives

- personal consequences
    - loss of reputation
    - loss of job
- company consequences
    - cost
    - schedule
- public consequences
    - worst case, loss of life

Theme 4. Understand, be familiar, or proficient

- mechanical
    - understand, needs help occasionally
    - enough for creative thinking
    - basic understanding
    - proficient
    - understand
    - rudimentary understanding
- software
    - competent
    - understand
- evaluation and procedures
    - understands and doesn't need help
    - needs help occasionally
    - deep understanding
    - familiar
    - understand
    - full, almost expert
    - proficient
    - know enough
    - access information

Theme 5. The Interpreter, or the bridge between the design engineer and the shop floor

- talk about processes in laymen's terms
- cooperative effort
- bridge between the design engineer and the shop floor

Theme 6. The storyteller, or make your data tell a story

- make your data tell a story
- where, why, and how to access information