Reimagining Manufacturing Education: Strategies to Engage First-year Engineering Students in Manufacturing Career Opportunities

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Abstract

Manufacturing is critical to the U.S. economy; however, it continues to face negative perceptions among young people, including engineering students. Despite industry advancements, many students still view manufacturing as outdated, low-skill work, largely due to limited exposure to modern practices, and many believe that it primarily pertains to specific engineering fields. This opinion paper introduces an educational approach we took to address these misconceptions and proposes direction for future efforts. To address the misconceptions of students, we introduced approaches, such as interactive guest lectures and hands-on data analysis in our first-year general engineering course. The guest lecturer elucidated on the collaborative nature of manufacturing, where teamwork across various engineering disciplines, such as materials engineering, computer engineering, and industrial engineering, drives innovation. Students also had chances to analyze manufacturing data for optimization purposes to explore different aspects of manufacturing. While some students remained uncertain about pursuing careers in manufacturing, they articulated a newfound appreciation for the field's relevance, complexity, and the diverse career paths it offers, including sustainability and process optimization. The instructional team's observation of the student's reaction revealed a transformative shift in their understanding of manufacturing. Students expressed surprise at advanced technologies such as metal 3D printing and powder bed fusion, recognizing the critical role engineers play in designing and optimizing these processes.

In addition to what we already tried in our classroom, as potential future approaches, we recommend future expansions into AR/VR applications, industry collaborations, and immersive project-based experiences to better introduce manufacturing to engineering students. These approaches aim to develop both technical competence and interdisciplinary thinking, essential for success in modern manufacturing. Furthermore, this paper will discuss actionable strategies for educators and industry leaders to inspire students, including manufacturing expos, mentorship programs, and integrated internships, all designed to bridge the gap between classroom learning and real-world applications. This study calls on educators and industry partners to reframe the narrative around manufacturing careers. By providing students with modern, engaging, and globally relevant learning experiences, we can spark sustained interest in manufacturing and prepare future engineers with the skills needed to thrive.

Introduction

Manufacturing has long been a cornerstone of the U.S. economy, contributing to job creation, innovation, and global competitiveness [1]. Despite its critical role, manufacturing faces a dual crisis: a skills gap including automation, robotics, IoT, data analytics, and AI-enabled systems, and a negative perception among young people, including engineering students [2]. Many of these students, influenced by outdated stereotypes and limited exposure to modern manufacturing practices, often view the field as synonymous with low-skill work in antiquated factories [3]. This perception not only undermines the industry's relevance but also discourages talented individuals from pursuing careers in manufacturing, which are essential for the advancement of technology and the sustainability of the industry.

This paper aims to address these misconceptions among first-year engineering students by proposing educational strategies to reshape their understanding of manufacturing. A significant portion of students entering engineering programs harbor misconceptions about the manufacturing sector, associating it primarily with assembly lines and manual labor. These views, rooted in historical contexts and media portrayals, overlook the technological advancements and interdisciplinary nature of modern manufacturing [4]. The disconnect between students' perceptions of manufacturing and the reality of the industry poses a significant challenge for educators and industry leaders. Research indicates that students' early career decisions are heavily influenced by their perceptions of various fields [5]. If students continue to view manufacturing as outdated, they are less likely to pursue careers in this vital sector, exacerbating the existing skills gap. The U.S. manufacturing sector is projected to grow; however, it will require a workforce equipped with advanced skills to meet the demands of modern production technologies [6].

The misconceptions surrounding manufacturing among first-year engineering students may represent a barrier to attracting new talent to the sector. Therefore, this study underscores the importance of reframing the narrative around manufacturing careers through innovative educational approaches. By providing students with modern, engaging, and globally relevant learning experiences, educators and industry leaders can inspire a new generation of engineers who appreciate the complexities and opportunities within the manufacturing sector. The strategies proposed in this paper seek to cultivate sustained interest in manufacturing, which is essential for the industry's growth and global competitiveness.

Perceptions of Manufacturing

Manufacturing holds a pivotal role in the U.S. economy, yet it often suffers from negative perceptions, including engineering workforce [2]. This disconnect is rooted in historical narratives that frame manufacturing as an outdated industry, reliant on low-skill labor [7]. The decline of traditional manufacturing jobs, exacerbated by globalization and technological advancement, has contributed to this perception [8]. Balsmeier and Woerter (2019) note that while manufacturing jobs have diminished, the industry has transformed, evolving into a sphere characterized by advanced technologies and high-skilled labor [9]. However, students frequently associate manufacturing with images of assembly lines and low-wage work, failing to recognize the sophistication and innovation that define modern manufacturing practices [7], [26]. Media portrayals further entrench these misconceptions, often emphasizing factory closures and job losses without highlighting the ongoing transformation within the sector [4]. Negative media narratives shape public perceptions, leading to a lack of awareness about the diverse and exciting career opportunities available in manufacturing [2]. Consequently, many students enter engineering programs with preconceived notions that limit their enthusiasm for pursuing careers in this field.

However, contemporary manufacturing is a highly advanced, knowledge-intensive sector that underpins economic competitiveness and innovation. Smart manufacturing and Industry 4.0 technologies, such as industrial internet of things, cyber-physical systems, artificial intelligence, robotics, and big data analytics are transforming factories into smart factories that are connected, flexible, and optimized in real time [10], [11]. Contemporary manufacturing encompasses a range of high-tech processes, including automation, robotics, and advanced materials [12]. The integration of technologies such as 3D printing, Artificial intelligence (AI), and the Internet of Things (IoT) has transformed manufacturing into a dynamic and innovative field, requiring a diverse skill set that spans multiple engineering disciplines [13]. Rather than relying primarily on low-skilled labor, modern production systems demand engineers and technologists who can integrate digital tools, analyze complex datasets, improve processes, and design sustainable solutions [14]. These systems support higher productivity, better quality, and reduced environmental impact, aligning manufacturing with broader goals of sustainability 4.0 and circular economy practices [15]. Consequently, manufacturing today offers intellectually challenging, well-remunerated careers in areas such as automation, data-driven decision-making, sustainable production, and digital transformation, far removed from traditional images of repetitive, manual work [14], [15].

As the landscape of manufacturing continues to evolve, so do the career opportunities available to engineering graduates as well. The future of manufacturing is increasingly characterized by sustainability, technological advancement, and innovation. Mohamed et al. [16] emphasize that sustainability is becoming a driving force in manufacturing, with companies seeking engineers who can develop sustainable practices and processes. This shift presents an opportunity for students to engage in meaningful work that addresses pressing global challenges, such as climate change and resource management. Companies are not only looking to reduce waste and emissions but also to harness renewable energy sources, which require engineers who understand sustainable material selection and lifecycle assessments. Additionally, the development of circular supply chains is gaining traction, allowing for the recycling and repurposing of materials, thereby minimizing environmental impact and creating new job opportunities in engineering roles focused on sustainability [17], [18].

Technological advancements, particularly in automation and artificial intelligence, are reshaping job roles within manufacturing [19]. Routine tasks are becoming automated, and the demand for engineers skilled in data analysis and system optimization is increasing [19]. This evolution necessitates a workforce that is adaptable and equipped with the skills to navigate the complexities of modern manufacturing environments. For example, robotic process automation (RPA) is being implemented for tasks such as assembly and quality control, significantly increasing efficiency and precision [20]. Furthermore, AI systems are now being used for predictive maintenance, which allows companies to foresee equipment failures before they occur, reducing downtime and saving costs [21]. Machine learning algorithms can analyze vast amounts of production data to optimize workflows in real time, leading to smarter factory environments [21]. Consequently, educators need to prioritize curriculum alignment with industry trends, ensuring that students acquire the competencies needed to thrive in this changing landscape.

Without exposure to these advancements, students are likely to retain outdated perceptions. The misconceptions towards modern manufacturing have significant implications for career aspirations among engineering students. Research indicates that most students express minimal interest in manufacturing careers, often viewing them as unappealing compared to other engineering careers [22]. The consequences of this perception extend beyond individual career choices. This lack of student interest can have long-term effects on workforce development, as the industry faces a talent shortage exacerbated by a failure to attract young engineers. As the manufacturing workforce ages, many skilled workers are retiring without a sufficient influx of new talent to replace them [23]. This gap threatens the innovative capacity of the industry and its ability to compete globally.

Research has shown that perceptions of manufacturing among students, particularly in engineering disciplines, are often influenced by a lack of exposure to modern practices and technologies [2]. Therefore, offering opportunities for students to explore modern manufacturing practices and diverse career pathways available within modern manufacturing will be helpful for inspiring students. Roles in design, process optimization, and sustainability are becoming increasingly prominent, offering promising opportunities for engineers to make an impact [25]. By fostering a new generation of engineers who appreciate and engage with the manufacturing sector, we can ensure a robust workforce capable of addressing future challenges, including sustainability and technological advancement [24].

Educational Strategies: An Example and Suggestions

An Example

Educational interventions can play a critical role in reshaping students' views on manufacturing. To enhance students' understanding of manufacturing careers, we introduced a manufacturing module into our first-year engineering program at Virginia Tech. We implemented several educational approaches aimed at fostering student interest and understanding of the manufacturing process. The session began with thought-provoking questions, prompting students to define manufacturing and reflect on its role in everyday products such as food, smartphones, and clothing. Students' initial responses to the instructor questions indicated a lack of enthusiasm for manufacturing, but as students identified various raw materials involved in these products, they started to make a connection between these materials to the broader manufacturing processes. The instructor emphasized manufacturing as a transformative process that converts raw materials into impactful products, reinforcing its relevance to engineering innovation and economic development. This transition from abstract to concrete facilitated deeper engagement, leading to a more dynamic class discussion.

In an educational environment, the delivery method of content is an essential part of instructional decision-making to maximize the impact of the intervention. Guest lectures from industry professionals can enhance students' understanding of manufacturing's collaborative and interdisciplinary nature. By engaging with practitioners who can articulate the complexities and innovations within the field, students can develop a more nuanced appreciation for the diverse career paths available in manufacturing. Sara and Arienne [27] highlight the positive impact of guest speakers on student engagement, as they can share their experiences and showcase the diverse career paths available within the industry. By hearing directly from professionals, students can gain a more nuanced understanding of manufacturing, moving beyond stereotypes to appreciate its relevance in today's economy.

Because of this reason, while introducing the manufacturing module in our first-year engineering program, we employed a guest lecture featuring an expert from industrial and systems engineering who could provide firsthand insights into the collaborative and interdisciplinary nature of manufacturing. We invited a guest lecturer to introduce cutting-edge technologies such as metal 3D printing. The invited speaker shared insights into laser powder bed fusion, showcasing real-world applications and challenges in the field. Students were encouraged to think critically about manufacturing processes by participating in group tasks that required them to consider design improvements in well-known products. These activities not only fostered collaboration but also stimulated critical thinking about sustainability and ethics in manufacturing.

After the guest lecture, we engaged students in hands-on activities involving the use of MATLAB for data analysis using data from the metal additive manufacturing process, specifically examining the laser powder bed fusion process. This helped students with interests in computer-related majors to relate more with manufacturing. The objective was to investigate how varying specific design parameters and machine settings impacted the thermal history of manufactured parts, ultimately affecting their quality. Using real manufacturing-related sensor data, students analyzed pixel intensity data to infer temperature variations during the build process. They calibrated multiple design cubes under different conditions, assessing how variables like laser power and scan speed contributed to issues such as warping and cracking. This experience emphasized data interpretation and its relevance to sustainable manufacturing practices, effectively allowing students to connect theoretical knowledge with real-world applications. This activity helped reposition manufacturing as a data-intensive and analytical field, particularly resonating with students interested in computing-related disciplines.

Suggestions

Beyond our classroom interventions, integrating cutting-edge technologies into manufacturing education is essential for engaging students and equipping them with relevant skills. Advanced technologies, such as additive manufacturing (AM), automation, and artificial intelligence (AI), are revolutionizing manufacturing processes and reshaping the skills required in the workforce. Mohsen [28] discusses how 3D printing not only enhances product design but also enables rapid prototyping and customization, which are increasingly important in today's market. Exposure to these technologies in educational settings can significantly alter students' perceptions of manufacturing, making it more appealing and relevant.

Research indicates that familiarity with cutting-edge technologies can enhance student interest in manufacturing careers. For example, Hengtao and Ramy [29] found that students exposed to modern manufacturing technologies during their coursework demonstrated a greater excitement towards pursuing careers in the field.

Moreover, the hands-on experience gained from working with technologies such as robotics and automation systems can help students appreciate the complexities of manufacturing and the engineering expertise required to optimize these processes. For example, an undergraduate engineering design class uses 3D printers as additional tools alongside computer-aided design (CAD). Students first create virtual 3D models, then print their designs, which helps them better understand geometry, tolerances, and manufacturability while gaining basic additive manufacturing skills and motivation to participate in face-to-face activities [30], [31]. A second example is a project-based course where students design assistive devices for people with disabilities and fabricate them using additive manufacturing. Teams learn the fundamentals of AM processes and materials, then complete full engineering projects such as a medicine-bottle opener or a device for pouring liquids for people with Parkinson's disease, iterating designs based on testing and quality control of printed parts [31]. In both cases, students move beyond abstract theory to experience the full cycle of modern manufacturing, digital modeling, physical fabrication, testing, and redesign, supporting creativity, engagement, and deeper understanding of manufacturing concepts [30], [31].

Emerging technologies such as augmented and virtual reality (AR/VR) can further enhance manufacturing education by providing immersive learning experiences. For example, AR/VR technologies are emerging as powerful tools in manufacturing education, providing immersive learning experiences that can deepen understanding and engagement. Eren [32] highlights the potential of AR/VR to simulate manufacturing environments, allowing students to experiment with processes and understand the implications of their design choices. For instance, students can virtually navigate a manufacturing facility, interact with machinery, and visualize complex systems, thereby gaining insights that traditional classroom settings may not provide.

Looking ahead, curriculum development must prioritize the integration of content related to modern manufacturing technologies, such as automation and data analytics, to align educational offerings with industry needs. For successful educational innovation with industry alignment, instructors can leverage partnerships with industry. Partnerships with industry can facilitate experiential learning opportunities, such as internships and project-based collaborations, that bridge the gap between classroom knowledge and real-world applications. For example, Leena and Yrjo [33] recommends forming partnerships with local industries to provide students with exposure to cutting-edge practices and tools. As the future of manufacturing increasingly emphasizes sustainability and proficiency in modern technologies, educational institutions could also align their curricula with these trends. This alignment will prepare students for the evolving workforce and stimulate sustained interest in manufacturing careers.

To sum, to effectively inspire the next generation of engineers, we recommend the following actionable strategies:

1. Integrate modern manufacturing technologies and practices into engineering programs, ensuring that students develop relevant skills for the future workforce.
2. Establish partnerships with local manufacturing companies to provide students with hands- on experiences through internships, workshops, and guest lectures.
3. Utilize immersive technologies like AR and VR to create engaging and interactive learning experiences that showcase the complexities of manufacturing processes.
4. Encourage collaborative projects that bring together students from various engineering disciplines, highlighting the teamwork required in real-world manufacturing environments.
5. Actively work to change the perception of manufacturing through outreach programs, career expos, and mentorship opportunities that showcase the rewarding and impactful nature of careers in this field.

By implementing these recommendations in a coordinated and sustained manner, educators and industry partners can move beyond one-off interventions to create a coherent Education 4.0 ecosystem that mirrors the realities of Industry 4.0 and emerging Industry 5.0 manufacturing environments. Embedding advanced tools such as additive manufacturing, mixed/virtual reality, and smart factory concepts into first-year experiences not only counters outdated images of manufacturing but also builds the digital, interdisciplinary, and sustainability-oriented competences demanded by modern production systems. When combined with project-based learning, industry-integrated curricula, and robust internship and mentoring pathways, these strategies help close the skills and perception gaps simultaneously, positioning manufacturing as an innovative, human-centric, and socially impactful career destination for the next generation of engineers. This will help inspire a new generation of engineers to view manufacturing as a dynamic and rewarding career path.

Conclusion

The landscape of manufacturing is undergoing a transformative evolution, yet the perceptions held by first-year engineering students often lag these advancements. This paper addresses misconceptions that portray manufacturing as low-skill and monotonous. By examining these perceptions, we underscore the importance of reframing the narrative to reflect the complexity, innovation, and interdisciplinary nature of modern manufacturing. In response to these misconceptions, educational strategies must adapt to better engage students. The effectiveness of interactive guest lectures featuring an expert from industrial and systems engineering and data analysis where we employed manufacturing-related data has been demonstrated, providing students with insights into the collaborative and dynamic environment of manufacturing. These experiences serve to illuminate the diverse career paths available, including roles focused on sustainability, process optimization, and technological innovation. Furthermore, integrating advanced technologies such as 3D printing and augmented reality into the curriculum can significantly enhance student engagement and understanding, enhancing the appeal and relevance of manufacturing education. By fostering a modern educational landscape that embraces innovative technologies and collaborative partnerships, we can inspire a new generation of engineers to recognize manufacturing as a dynamic, impactful, and fulfilling career path.

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