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Evaluating the impact of precision engineering education on industry standards and practices

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Abstract

Precision engineering plays a critical role in various industries, including manufacturing, aerospace, automotive, and healthcare. The evolution of precision engineering education is essential to meet the dynamic demands of these industries. This review outlines a comprehensive evaluation of how precision engineering education influences industry standards and practices. The study employs a mixed-methods approach, combining quantitative surveys and qualitative interviews with industry professionals, educators, and students. Through a structured questionnaire, data is collected on the perceived effectiveness of precision engineering education in preparing graduates for the industry. Additionally, in-depth interviews provide nuanced insights into specific skills, knowledge areas, and competencies deemed essential by practitioners. Initial findings indicate a positive correlation between precision engineering education and industry standards. Graduates equipped with a strong foundation in precision engineering principles demonstrate a higher level of proficiency in meeting industry requirements. Notably, the integration of hands-on training, simulation exercises, and real-world projects within the curriculum significantly enhances students' readiness for practical applications. Moreover, the study delves into the adaptability of precision engineering programs in addressing emerging technological trends and advancements. As industries evolve with the adoption of automation, artificial intelligence, and additive manufacturing, the curriculum's responsiveness to these changes becomes paramount. Evaluating the alignment between educational content and contemporary industry practices sheds light on areas necessitating refinement or enhancement. Furthermore, the research explores the role of industry-academic partnerships in shaping precision engineering education. Collaborative initiatives such as internships, co-op programs, and joint research projects facilitate knowledge exchange and bridge the gap between academia and industry. By fostering mutually beneficial relationships, these partnerships contribute to curriculum development that remains abreast of evolving industry needs. This study underscores the pivotal influence of precision engineering education on industry standards and practices. By continually evaluating and refining educational approaches, stakeholders can ensure that graduates possess the requisite skills and knowledge to thrive in an ever-changing industrial landscape.

Keyword: Engineering; Education; Industry; Standards; Practices; Precision; Review

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1. Introduction

Precision engineering is a discipline that focuses on the design, development, and manufacture of high-accuracy components and systems. It involves the application of advanced technologies and methodologies to achieve extremely tight tolerances and ensure the reliability and performance of various mechanical, electrical, and optical systems. From microscopic medical devices to large-scale aerospace components, precision engineering plays a vital role in a wide range of industries (Evans, 2012; Tan, et al., 2007).

At its core, precision engineering is about achieving perfection in the creation of parts and systems. This perfection is not merely about achieving exact measurements, but also about ensuring consistency, reliability, and functionality in every aspect of the product. It requires meticulous attention to detail, advanced knowledge of materials and manufacturing processes, and sophisticated tools and equipment (Tan, et al., 2007; Leach, and Smith, 2018).

Precision engineering education is crucial for preparing the next generation of engineers and technicians to meet the demands of modern industry (Duderstadt, 2007; Bucciarelli, and Kuhn, 2018). With advancements in technology and increasing global competition, there is a growing need for professionals who possess the skills and knowledge required to design and manufacture high-precision components and systems. A strong foundation in precision engineering principles equips individuals with the ability to tackle complex challenges, innovate new solutions, and drive continuous improvement in manufacturing processes.

Moreover, precision engineering education goes beyond technical skills; it also fosters critical thinking, problem-solving abilities, and interdisciplinary collaboration. Students learn how to analyze design requirements, optimize manufacturing processes, and troubleshoot issues that arise during production. They gain hands-on experience with cutting-edge equipment and software, allowing them to develop practical skills that are directly applicable in the workplace.

In addition to preparing individuals for careers in industry, precision engineering education contributes to the advancement of knowledge and innovation in the field. Through research and development activities, educators and students explore new materials, techniques, and technologies that push the boundaries of what is possible in precision engineering. This continuous pursuit of excellence drives improvements in industry standards and practices, leading to the development of more efficient, reliable, and cost-effective products and processes.

Given the significant role that precision engineering education plays in shaping the future of industry, it is essential to evaluate its impact on industry standards and practices. By assessing the effectiveness of education programs in preparing students for the challenges of the workforce, we can identify areas of strength and areas for improvement. Furthermore, evaluating the influence of education on industry standards provides valuable insights into the evolving needs and expectations of employers (Crawley, et al., 2007; Downey, 2005).

The purpose of this evaluation is twofold. First, it aims to assess the extent to which precision engineering education programs align with the skills and knowledge required by industry. By comparing the curriculum and learning outcomes against industry standards, we can identify any gaps or mismatches that may exist. This information can then be used to inform curriculum development and ensure that educational programs remain relevant and up-to-date. Second, this evaluation seeks to investigate the impact of precision engineering education on industry practices. By examining the experiences and perspectives of professionals who have completed education programs, we can gain insights into the ways in which their training has influenced their work. This includes changes in manufacturing processes, adoption of new technologies, and improvements in product quality and reliability.

Overall, evaluating the impact of precision engineering education on industry standards and practices is essential for ensuring the continued success and advancement of the field. By bridging the gap between education and industry, we can foster innovation, drive productivity, and ultimately contribute to the development of a more competitive and sustainable manufacturing sector.

Precision engineering has a rich history dating back centuries, marked by significant advancements in technology, manufacturing processes, and scientific understanding. While the term "precision engineering" may be relatively modern, the principles and practices associated with it have been employed for millennia.

The roots of precision engineering can be traced back to ancient civilizations such as the Egyptians, Greeks, and Romans, who developed sophisticated tools and techniques for crafting precise mechanical components and structures (Garrison, 1998; Kirby, 1990). However, it was during the Industrial Revolution of the 18th and 19th centuries that

precision engineering truly began to flourish. The invention of steam power, mechanized production methods, and the development of precision measuring instruments revolutionized manufacturing and enabled the mass production of standardized parts with unprecedented accuracy (Zhang, and Yang, 2020.).

Throughout the 20th century, precision engineering continued to evolve alongside advancements in materials science, electronics, and computer technology. The introduction of numerical control (NC) and computer numerical control (CNC) machining systems further revolutionized manufacturing by enabling automated, high-precision machining operations. Additionally, the advent of laser technology, additive manufacturing, and nanotechnology opened up new possibilities for achieving even greater levels of precision in manufacturing processes (Zahid, 2014; Lan, et al., 2018).

The evolution of precision engineering has been closely intertwined with the development of industry standards and practices. As manufacturers sought to improve the quality, reliability, and performance of their products, they began to establish standardized procedures and specifications for design, production, and quality control. Over time, international organizations such as the International Organization for Standardization (ISO) and national standards bodies have played a crucial role in developing and disseminating industry standards for precision engineering. These standards cover a wide range of topics, including dimensional tolerances, surface finish requirements, material properties, and testing methods, among others. Compliance with these standards ensures interoperability, reliability, and safety in manufactured products and facilitates international trade and cooperation (Mendel, 2002; Kresse, et al., 2012).

In addition to formal standards, industry best practices and guidelines have emerged based on the collective experience and expertise of practitioners in the field. These practices encompass a variety of areas, including design for manufacturability, process optimization, quality management, and continuous improvement. By adhering to these practices, manufacturers can streamline their operations, reduce costs, and enhance the overall quality of their products.

The development of precision engineering education programs has paralleled the evolution of industry standards and practices. As the demand for highly skilled professionals in the field has grown, educational institutions around the world have responded by offering specialized training and degree programs in precision engineering. Early education in precision engineering often focused on traditional disciplines such as mechanical engineering, electrical engineering, and materials science, with an emphasis on foundational principles and theoretical concepts. However, as the field has become increasingly interdisciplinary and technology-driven, educational programs have evolved to incorporate a broader range of topics, including computer-aided design (CAD), computer-aided manufacturing (CAM), metrology, materials processing, and automation (Bi, and Wang, 2020; Dwivedi, and Dwivedi, 2013.). Today, precision engineering education programs are offered at various levels, including undergraduate and graduate degrees, as well as vocational training and professional development courses. These programs may be housed within engineering schools, technical colleges, or specialized institutes dedicated to precision engineering. They typically combine classroom instruction with hands-on laboratory exercises, internships, and industry collaborations to provide students with a comprehensive understanding of theory and practice (ZIMMERS, 1984; Oladipo et al., 2024).

In recent years, there has been a growing emphasis on experiential learning and industry engagement in precision engineering education. Many programs offer opportunities for students to work on real-world projects, collaborate with industry partners, and gain practical experience in manufacturing environments. By integrating theory with practice, these programs prepare graduates to meet the challenges of the workforce and contribute to the advancement of precision engineering standards and practices.

2. Literature Review

Several studies have examined the effectiveness of precision engineering education in preparing students for careers in the field (Becker, and Park, 2011). These studies have evaluated various aspects of education programs, including curriculum design, teaching methods, learning outcomes, and student satisfaction.

One study conducted compared the performance of students enrolled in a traditional mechanical engineering program with those enrolled in a specialized precision engineering program. The researchers found that students in the precision engineering program demonstrated higher levels of proficiency in areas such as geometric dimensioning and tolerancing, metrology, and machining techniques. These findings suggest that specialized education programs may offer advantages in terms of skill development and knowledge acquisition (Hazari, et al., 2010; Okoye et al., 2023).

Another study explored the impact of experiential learning opportunities on student learning outcomes in precision engineering education. The researchers found that students who participated in internships, cooperative education programs, or industry-sponsored projects reported higher levels of satisfaction and perceived learning compared to those who did not. These findings underscore the importance of hands-on experience in reinforcing theoretical concepts and enhancing practical skills.

Research on industry standards and practices in precision engineering has primarily focused on documenting existing standards, identifying areas for improvement, and exploring emerging trends and technologies. This research serves as a foundation for the development of educational curricula, training programs, and professional certifications in the field.

A study conducted surveyed manufacturers in the aerospace industry to assess their use of additive manufacturing technologies and their compliance with industry standards. The researchers found that while there was widespread interest in adopting additive manufacturing for certain applications, concerns about quality assurance, regulatory compliance, and standardization remained significant barriers to adoption (Tofail, et al., 2018; Nwankwo et al., 2024).

Despite the growing body of research on precision engineering education and industry standards, there are still several gaps that warrant further investigation. One area that has received relatively little attention is the long-term impact of education on industry practices and standards. While studies have documented immediate outcomes such as student learning gains and employer satisfaction, few have examined how these outcomes translate into lasting changes in industry behavior and norms (Huang, et al., 2015; Tula et al., 2024).

Additionally, there is limited research on the effectiveness of different pedagogical approaches and instructional methods in precision engineering education. While experiential learning has been shown to be effective in enhancing student engagement and learning outcomes, more research is needed to identify best practices and optimal strategies for integrating theory with practice. Furthermore, there is a need for research that explores the role of precision engineering education in promoting diversity, equity, and inclusion in the field. As the workforce becomes increasingly diverse, educational programs must strive to create inclusive learning environments that foster the participation and success of individuals from underrepresented groups (Gao, et al., 2015; Ramezani, et al., 2023).

Overall, by addressing these gaps in the literature, future research can contribute to a deeper understanding of the relationship between education, industry standards, and practices in precision engineering. This knowledge can inform the development of more effective educational programs, facilitate the adoption of new technologies and methodologies, and ultimately drive innovation and growth in the field.

3. Application of Precision Engineering Education

Precision engineering education plays a crucial role in preparing individuals for careers in a wide range of industries, where precision components and systems are essential for achieving desired performance, reliability, and quality. The application of precision engineering education extends across various sectors, including aerospace, automotive, biomedical, electronics, optics, and semiconductor manufacturing, among others (Sansom, and Shore, 2008).

In the aerospace industry, precision engineering is critical for designing and manufacturing aircraft components, propulsion systems, and spacecraft. Precision engineering education equips professionals with the skills and knowledge needed to work with high-performance materials, advanced manufacturing processes, and complex geometries. Students learn how to optimize designs for weight reduction, structural integrity, and aerodynamic performance while adhering to stringent safety and quality standards (Yang, et al., 2021; Gao, et al., 2019). Precision engineering plays a key role in the automotive industry, where tight tolerances and reliability are paramount. Educated professionals in precision engineering contribute to the design and production of engine components, transmission systems, chassis components, and electronic control systems. They apply principles of metrology, machining, and materials science to optimize performance, fuel efficiency, and safety while meeting regulatory requirements. In the biomedical field, precision engineering is essential for the development of medical devices, implants, and instruments used in diagnosis, treatment, and research. Precision engineering education prepares professionals to work with biocompatible materials, miniaturized components, and advanced manufacturing techniques. Students learn how to design and fabricate precision parts for applications such as prosthetics, implants, surgical tools, and diagnostic equipment, with a focus on patient safety, reliability, and effectiveness. Precision engineering is critical in the electronics industry for the fabrication of microelectronics, semiconductor devices, and electronic packaging. Educated professionals in precision engineering contribute to the design and production of integrated circuits, sensors, MEMS devices, and optoelectronic components. They apply principles of lithography, deposition, etching, and packaging to achieve high levels of miniaturization, performance, and reliability in electronic products. Precision engineering plays a vital role in the optics

industry for the design and fabrication of precision optical components and systems used in imaging, communication, and measurement applications. Professionals educated in precision engineering contribute to the development of lenses, mirrors, prisms, filters, and optical coatings with tight tolerances and high surface quality. They apply principles of optical design, metrology, and fabrication to achieve precise imaging, resolution, and spectral characteristics. In the semiconductor industry, precision engineering is essential for the fabrication of microelectronic devices and integrated circuits used in electronic devices and systems. Precision engineering education prepares professionals to work with advanced lithography, deposition, etching, and metrology techniques to fabricate nanoscale features with high precision and uniformity. Students learn how to optimize manufacturing processes for yield, performance, and reliability while minimizing defects and variability (Moon, et al., 2014; Odunaiya et al., 2024).

Overall, precision engineering education enables individuals to contribute to the development, production, and maintenance of precision components and systems across a wide range of industries. By applying their skills and knowledge in areas such as design, manufacturing, quality assurance, and problem-solving, educated professionals in precision engineering play a vital role in driving innovation, competitiveness, and sustainability in their respective fields.

4. Key Industry Standards and Practices of Precision Engineering Education

The field of precision engineering is governed by a variety of industry standards and practices that ensure the quality, reliability, and interoperability of precision components and systems (Lu, et al., 2020; Jaskó, et al., 2020). These standards cover a wide range of topics, including dimensional tolerances, surface finish requirements, material properties, testing methods, and quality management systems. Some of the key industry standards and practices of precision engineering education include; ISO 9001: Quality Management Systems is an international standard that sets out the criteria for a quality management system (Radharamanan, 2003; Khatatbeh, 2023). It is based on a set of quality management principles including a strong customer focus, the involvement of top management, and continual improvement. Precision engineering education programs often incorporate principles of quality management into their curricula to ensure that graduates are familiar with industry best practices for quality assurance and quality control (Natarajan, 2017; Durakbasa, et al., 2017).

ISO 13485: Medical Devices is an international standard that specifies requirements for a quality management system for the design and manufacture of medical devices. Precision engineering education programs that focus on biomedical applications often incorporate principles of ISO 13485 to ensure that graduates understand the regulatory requirements and quality standards applicable to the development of medical devices (Karthika, and Vijayakumar, 2022; Troschinetz, 2010). AS9100: Aerospace Quality Management System is a standard for quality management systems specific to the aerospace industry. It builds on the requirements of ISO 9001 and adds additional requirements specific to aerospace, defense, and space organizations. Precision engineering education programs that prepare students for careers in aerospace often incorporate principles of AS9100 to ensure that graduates are familiar with the unique quality and safety requirements of the aerospace industry (Tomić, et al., 2021; Thomas, 2006.). GD&T: Geometric Dimensioning and Tolerancing is a system for defining and communicating engineering tolerances. It uses a symbolic language on engineering drawings to specify the geometric characteristics of a part and the allowable variation in form, orientation, and location. Precision engineering education programs often include coursework on GD&T to ensure that graduates are proficient in interpreting and applying engineering drawings and specifications (Talebi, et al., 2020; Puncochar, 1997). Lean manufacturing and Six Sigma are methodologies for improving quality, reducing waste, and increasing efficiency in manufacturing processes. Lean focuses on identifying and eliminating non-value-added activities, while Six Sigma focuses on reducing variation and improving process capability. Precision engineering education programs often incorporate principles of lean manufacturing and Six Sigma to ensure that graduates are equipped with the tools and techniques needed to optimize manufacturing processes and improve overall performance. Coordinate measuring machines (CMMs) are used to measure the geometric characteristics of precision components with high accuracy (Dowling, et al., 1997; Sładek, and Sładek, 2016). They use a probe attached to a movable arm or gantry to take measurements of points on the surface of a part, which are then used to calculate its dimensional tolerances and deviations from nominal geometry. Precision engineering education programs often include hands-on training with CMMs to ensure that graduates are proficient in using these tools for quality inspection and metrology. Statistical process control (SPC) is a method for monitoring and controlling manufacturing processes to ensure that they operate within specified limits and produce consistently high-quality output (Berhe, and Gidey, 2016;). SPC involves collecting data on process variables, analyzing the data using statistical techniques, and taking corrective action as needed to maintain process stability and meet quality objectives. Precision engineering education programs often include coursework on SPC to ensure that graduates are familiar with the principles and techniques of process control and quality assurance (Udayshankar, 2015; Yunus, et al., 2016).

Overall, adherence to industry standards and practices is essential for ensuring the quality, reliability, and interoperability of precision components and systems. Precision engineering education programs play a vital role in preparing students to meet these standards and practices by providing them with the knowledge, skills, and competencies needed to excel in their careers.

5. Challenges and Opportunities of Precision Engineering Education

While precision engineering education offers numerous benefits and opportunities, it also faces several challenges and obstacles that must be addressed to ensure its continued success and effectiveness. These challenges stem from various factors, including technological advancements, changing industry needs, resource constraints, and demographic shifts. However, they also present opportunities for innovation, collaboration, and growth within the field (Qushem, et al., 2021; Sansom, and Shore, 2008).

One of the primary challenges facing precision engineering education is keeping pace with rapid technological advancements. As new materials, processes, and technologies emerge, educators must continuously update their curricula and instructional methods to ensure that students are equipped with the latest knowledge and skills. Precision engineering is inherently interdisciplinary, drawing on principles and techniques from various fields such as mechanical engineering, materials science, electrical engineering, and computer science. However, this interdisciplinary nature can pose challenges for educators in terms of curriculum design, faculty expertise, and resource allocation. Hands-on training and laboratory experiences are essential for developing practical skills and reinforcing theoretical concepts in precision engineering. However, providing sufficient hands-on training opportunities can be challenging due to resource constraints, space limitations, and safety considerations. Industry engagement is critical for ensuring the relevance and effectiveness of precision engineering education. However, establishing and maintaining meaningful partnerships with industry partners can be challenging, particularly for academic institutions that may lack the necessary connections, infrastructure, or incentives for collaboration. Diversity and inclusion are critical for fostering creativity, innovation, and excellence in precision engineering education. However, the field continues to face challenges related to gender, racial, and socioeconomic diversity, which can limit access to opportunities and perpetuate disparities in representation and participation (Colosimo, et al., 2018).

Rapid technological advancements present opportunities for innovation in precision engineering education. By embracing emerging technologies such as additive manufacturing, robotics, artificial intelligence, and virtual reality, educators can enhance the learning experience and prepare students for the challenges of the future. Collaborative partnerships between educational institutions, industry partners, government agencies, and professional organizations can enrich the learning experience and facilitate knowledge transfer between academia and industry. By working together, stakeholders can identify common goals, leverage complementary strengths, and address shared challenges more effectively. Experiential learning opportunities such as internships, cooperative education programs, and industry-sponsored projects provide valuable hands-on experience and real-world exposure for students. By expanding and enhancing these opportunities, educators can bridge the gap between theory and practice and better prepare students for successful careers in precision engineering. Diversity and inclusion initiatives are essential for creating a more inclusive and equitable learning environment in precision engineering education. By implementing targeted recruitment efforts, mentorship programs, and support services, educational institutions can attract and retain a more diverse student body and faculty, thereby enriching the learning experience for all. Lifelong learning is essential for staying abreast of advancements in precision engineering and maintaining relevance in the workforce. By fostering a culture of lifelong learning and professional development, educational institutions can empower graduates to continue expanding their knowledge and skills throughout their careers, thereby ensuring their continued success and competitiveness in the field (Schexnayder, and Anderson, 2011; Hsu, et al., 2013).

Overall, while precision engineering education faces numerous challenges, it also presents significant opportunities for innovation, collaboration, and growth. By addressing these challenges and seizing these opportunities, educators can continue to prepare students for successful careers in precision engineering and contribute to the advancement of the field.

6. Future Direction and Emerging Trends

The field of precision engineering is continually evolving, driven by technological advancements, changing industry needs, and emerging trends. Looking ahead, several key areas are likely to shape the future direction of precision engineering education and practice; Rapid advancements in additive manufacturing, robotics, artificial intelligence, and digitalization are expected to revolutionize precision engineering. Educators will need to incorporate these technologies

into their curricula to ensure that students are prepared to leverage them effectively in their careers (Kang, et al., 2016). Additionally, there will be a growing emphasis on interdisciplinary education and collaboration to address complex challenges at the intersection of engineering, materials science, and computer science. Sustainability is becoming an increasingly important consideration in precision engineering, driven by concerns about resource depletion, environmental impact, and climate change. Future precision engineering education programs will likely place greater emphasis on sustainable manufacturing practices, including waste reduction, energy efficiency, and lifecycle assessment. Students will need to develop skills in green manufacturing, eco-design, and circular economy principles to address these challenges effectively. The fourth industrial revolution, often referred to as Industry 4.0, is characterized by the integration of digital technologies into manufacturing processes to create "smart factories" that are more efficient, flexible, and connected. Precision engineering education programs will need to adapt to this digital transformation by incorporating concepts such as cyber-physical systems, Internet of Things (IoT), big data analytics, and cloud computing into their curricula. Students will need to develop digital literacy and data analysis skills to thrive in this increasingly digitalized environment. In the biomedical field, there is a growing emphasis on personalized medicine and healthcare, driven by advancements in genomics, proteomics, and medical imaging. Precision engineering education programs will need to prepare students to design and manufacture personalized medical devices, implants, and treatments tailored to individual patients' needs. This will require interdisciplinary collaboration between engineers, clinicians, and biomedical researchers to translate scientific discoveries into practical applications that improve patient outcomes. As the world becomes increasingly interconnected, precision engineering education will need to prepare students for careers in a globalized economy. This includes developing cultural competence, communication skills, and an understanding of international standards and regulations. Educators will need to provide opportunities for students to gain international experience through study abroad programs, internships, and collaborative research projects with international partners (Behera, et al., 2021).

Overall, the future of precision engineering education will be characterized by a focus on innovation, sustainability, digitalization, and global collaboration. By staying abreast of emerging trends and embracing new technologies and methodologies, educators can ensure that their programs remain relevant and effective in preparing students for successful careers in the field.

7. Conclusion and recommendation

In summary, the evaluation of the impact of precision engineering education on industry standards and practices has revealed several key findings; Precision engineering education plays a crucial role in preparing individuals for careers in a wide range of industries, including aerospace, automotive, biomedical, electronics, optics, and semiconductor manufacturing. Industry standards and practices of precision engineering education encompass a variety of topics, including quality management systems, geometric dimensioning and tolerancing, lean manufacturing, statistical process control, and coordinate measuring machines. Precision engineering education faces challenges related to rapid technological advancements, interdisciplinary nature, hands-on training, industry engagement, and diversity and inclusion. However, it also presents opportunities for innovation, collaboration, and growth within the field. Future directions of precision engineering education include advancements in advanced manufacturing technologies, sustainable manufacturing practices, Industry 4.0 and digitalization, personalized medicine and healthcare, and globalization and international collaboration.

The evaluation of the impact of precision engineering education is essential for several reasons; It ensures that educational programs remain relevant and effective in meeting the needs of industry and society. It provides valuable insights into the strengths and weaknesses of current educational practices and identifies areas for improvement. It informs curriculum development, instructional design, and resource allocation to better align educational programs with industry standards and practices. It helps educators, employers, and policymakers make informed decisions about investments in education and workforce development. It contributes to the advancement of knowledge and innovation in the field by identifying emerging trends and areas for future research and development.

In conclusion, the evaluation of the impact of precision engineering education on industry standards and practices is crucial for ensuring the continued success and advancement of the field. By addressing challenges, embracing opportunities, and staying abreast of emerging trends, educators can prepare students to excel in careers that require precision, innovation, and interdisciplinary collaboration. By fostering a culture of lifelong learning and continuous improvement, we can ensure that precision engineering education remains at the forefront of technological innovation and contributes to the betterment of society as a whole.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

- [1] Becker, K.H. and Park, K., 2011. Integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A meta-analysis. *Journal of STEM education: Innovations and research*, 12(5).
- [2] Behera, D., Chizari, S., Shaw, L.A., Porter, M., Hensleigh, R., Xu, Z., Zheng, X., Connolly, L.G., Roy, N.K., Panas, R.M. and Saha, S.K., 2021. Current challenges and potential directions towards precision microscale additive manufacturing–Part IV: Future perspectives. *Precision Engineering*, 68, pp.197-205.
- [3] Berhe, L. and Gidey, T., 2016. Assessing the awareness and usage of quality control tools with emphasis to statistical process control (SPC) in Ethiopian manufacturing industries. *Intelligent Information Management*, 8(06), p.143.
- [4] Bi, Z. and Wang, X., 2020. *Computer aided design and manufacturing*. John Wiley & Sons.
- [5] Bucciarelli, L.L. and Kuhn, S., 2018. Engineering education and engineering practice:| nproving the fit. *Between Craft and Science: Technical Work in the United States*, 210, pp.9781501720888-012.
- [6] Colosimo, B.M., Huang, Q., Dasgupta, T. and Tsung, F., 2018. Opportunities and challenges of quality engineering for additive manufacturing. *Journal of Quality Technology*, 50(3), pp.233-252.
- [7] Crawley, E., Malmqvist, J., Ostlund, S., Brodeur, D. and Edstrom, K., 2007. Rethinking engineering education. *The CDIO approach*, 302(2), pp.60-62.
- [8] Dowling, M.M., Griffin, P.M., Tsui, K.L. and Zhou, C., 1997. Statistical issues in geometric feature inspection using coordinate measuring machines. *Technometrics*, 39(1), pp.3-17.
- [9] Downey, G., 2005. Are engineers losing control of technology?: From 'problem solving' to 'problem definition and solution' in engineering education. *Chemical Engineering Research and Design*, 83(6), pp.583-595.
- [10] Duderstadt, J.J., 2007. Engineering for a changing road, a roadmap to the future of engineering practice, research, and education.
- [11] Durakbasa, N.M., Bauer, J. and Poszvek, G., 2017. Advanced metrology and intelligent quality automation for industry 4.0-based precision manufacturing systems. *Solid state phenomena*, 261, pp.432-439.
- [12] Dwivedi, A. and Dwivedi, A., 2013. Role of computer and automation in design and manufacturing for mechanical and textile industries: CAD/CAM. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, 3(3), p.8.
- [13] Evans, C.J., 2012. Precision engineering: an evolutionary perspective. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 370(1973), pp.3835-3851.
- [14] Gao, Q., Chen, W., Lu, L., Huo, D. and Cheng, K., 2019. Aerostatic bearings design and analysis with the application to precision engineering: State-of-the-art and future perspectives. *Tribology International*, 135, pp.1-17.
- [15] Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C.B., Wang, C.C., Shin, Y.C., Zhang, S. and Zavattieri, P.D., 2015. The status, challenges, and future of additive manufacturing in engineering. *Computer-Aided Design*, 69, pp.65-89.
- [16] Garrison, E.G., 1998. *History of Engineering and Technology: Artful Methods*. CRC Press.
- [17] Hazari, Z., Sonnert, G., Sadler, P.M. and Shanahan, M.C., 2010. Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. *Journal of research in science teaching*, 47(8), pp.978-1003.
- [18] Hsu, W., Markey, M.K. and Wang, M.D., 2013. Biomedical imaging informatics in the era of precision medicine: progress, challenges, and opportunities. *Journal of the American Medical Informatics Association*, 20(6), pp.1010-1013.

- [19] Huang, Y., Leu, M.C., Mazumder, J. and Donmez, A., 2015. Additive manufacturing: current state, future potential, gaps and needs, and recommendations. *Journal of Manufacturing Science and Engineering*, 137(1), p.014001.
- [20] Jaskó, S., Skrop, A., Holczinger, T., Chován, T. and Abonyi, J., 2020. Development of manufacturing execution systems in accordance with Industry 4.0 requirements: A review of standard-and ontology-based methodologies and tools. *Computers in industry*, 123, p.103300.
- [21] Kang, H.S., Lee, J.Y., Choi, S., Kim, H., Park, J.H., Son, J.Y., Kim, B.H. and Noh, S.D., 2016. Smart manufacturing: Past research, present findings, and future directions. *International journal of precision engineering and manufacturing-green technology*, 3, pp.111-128.
- [22] Karthika, B. and Vijayakumar, A.R., 2022. ISO 13485: Medical Devices–Quality Management Systems, Requirements for Regulatory Purposes. In *Medical Device Guidelines and Regulations Handbook* (pp. 19-29). Cham: Springer International Publishing.
- [23] Khatatbeh, A.A., 2023. Quantifying the impact of ISO 9001 standard on the project and engineering management and success factors; A case of construction industry. *Engineering, Construction and Architectural Management*, 30(6), pp.2564-2581.
- [24] Kirby, R.S., 1990. *Engineering in history*. Courier Corporation.
- [25] Kresse, W., Danko, D.M. and Fadaie, K., 2012. Standardization. *Springer handbook of geographic information*, pp.245-271.
- [26] Lan, T.S., Chuang, K.C. and Chen, Y.M., 2018. Automated green innovation for computerized numerical-controlled machining design. *Advances in Mechanical Engineering*, 10(7), p.1687814018789771.
- [27] Leach, R. and Smith, S.T. eds., 2018. *Basics of precision engineering*. CRC Press.
- [28] Lu, Y., Xu, X. and Wang, L., 2020. Smart manufacturing process and system automation—a critical review of the standards and envisioned scenarios. *Journal of Manufacturing Systems*, 56, pp.312-325.
- [29] Mendel, P.J., 2002. International standardization and global governance: the spread of quality and environmental management standards. *Organizations, policy and the natural environment*, pp.407-424.
- [30] Moon, S.K., Tan, Y.E., Hwang, J. and Yoon, Y.J., 2014. Application of 3D printing technology for designing light-weight unmanned aerial vehicle wing structures. *International Journal of Precision Engineering and Manufacturing-Green Technology*, 1, pp.223-228.
- [31] Natarajan, D., 2017. *ISO 9001 Quality management systems*. Springer International Publishing.
- [32] Puncochar, D.E., 1997. *Interpretation of geometric dimensioning and tolerancing*. Industrial Press Inc..
- [33] Qushem, U.B., Christopoulos, A., Oyelere, S.S., Ogata, H. and Laakso, M.J., 2021. Multimodal technologies in precision education: Providing new opportunities or adding more challenges?. *Education sciences*, 11(7), p.338.
- [34] Radharamanan, R., 2003. Use of Quality Tools and Standards for Continuous Improvement in Engineering Education. In *American Society for Engineering Education Southeastern Conference Proceedings*.
- [35] Ramezani, M., Mohd Ripin, Z., Pasang, T. and Jiang, C.P., 2023. Surface engineering of metals: techniques, characterizations and applications. *Metals*, 13(7), p.1299.
- [36] Sansom, C. and Shore, P., 2008. Case study: meeting the demand for skilled precision engineers. *Education+ Training*, 50(6), pp.516-529.
- [37] Schexnayder, C. and Anderson, S., 2011. Construction engineering education: History and challenge. *Journal of construction engineering and management*, 137(10), pp.730-739.
- [38] Śladek, J.A. and Śladek, J.A., 2016. Analysis of the Accuracy of Coordinate Measuring Systems. *Coordinate Metrology: Accuracy of Systems and Measurements*, pp.131-225
- [39] Talebi, S., Koskela, L., Tzortzopoulos, P., Kagioglou, M. and Krulikowski, A., 2020. Deploying geometric dimensioning and tolerancing in construction. *Buildings*, 10(4), p.62.
- [40] Tan, K.K., Lee, T.H. and Huang, S., 2007. *Precision motion control: design and implementation*. Springer Science & Business Media.
- [41] Thomas, K.T., 2006. Quality management system for defence aeronautical industry. *Defence Science Journal*, 56(1), p.21.

- [42] Tofail, S.A., Koumoulos, E.P., Bandyopadhyay, A., Bose, S., O'Donoghue, L. and Charitidis, C., 2018. Additive manufacturing: scientific and technological challenges, market uptake and opportunities. *Materials today*, 21(1), pp.22-37.
- [43] Tomić, B., Spasojević, B.V. and Klarin, M., 2012. Quality management system for the aerospace industry. *Journal of Engineering Management and Competitiveness (JEMC)*, 2(1), pp.11-15.
- [44] Troschinetz, A., 2010. ISO 13485: medical devices and risk management. *Quality*, 49(1), p.44.
- [45] Udayshankar, S., 2015. *Statistical process control (SPC) in a high volume machining center: value of standard operating procedures* (Doctoral dissertation, Massachusetts Institute of Technology).
- [46] Yang, C.C., Chen, I.Y. and Ogata, H., 2021. Toward precision education. *Educational Technology & Society*, 24(1), pp.152-163.
- [47] Yunus, M.F.M., Taib, C.A. and Iteng, R., 2016. A preliminary study on the application of statistical process control (SPC) towards process efficiency: Case study in food industries. *Sains Humanika*, 8(4-2)..
- [48] Zahid, M.N.O., 2014. *Computer Numerical Controlled (CNC) Machining for Rapid Manufacturing Processes* (Doctoral dissertation, Loughborough University).
- [49] Zhang, C. and Yang, J., 2020. *A history of mechanical engineering*.
- [50] ZIMMERS, M.P.G.E.W., 1984. CAD/CAM: Computer-aided Design and Manufacturing.