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The Fourth Industrial Revolution: Opportunities and Challenges to the Future of Mechanical Engineering

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ABSTRACT

This paper provides a conceptual overview of the developments of the Fourth Industrial Revolution (4IR) and derives challenges and opportunities for the future of the mechanical engineering profession. The paper broadly defines 4IR as the fusion of technologies and interaction across physical, digital and biological aspects, while defining mechanical engineering as "a multi-faceted discipline that encompasses the teaching, practice and guidance of others in the development and application of scientific principles to mechanical systems". The paper looks specifically at developments in the Internet of Things (IoT), blockchain technology, robotics, Big Data analytics, biotechnology, nanotechnology, 3D printing and artificial intelligence and their impact on mechanical engineering. It will also explain the impact of 4IR and emerging fields such as electronic vehicles, mechatronics and others. The aim is to show that the world is in the age of 4IR, the impact of which will be felt in all professions, although the scale in general and the scope of mechanical engineering in particular cannot yet be properly assessed. The paper concludes by stating that the world is in the 4IR era, the impact of which will be felt in all professions and the future extent of which cannot be accurately estimated. The paper ends with a recommendation on the importance of mechatronics and soft skills.

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INTRODUCTION

One of the major development in technology today is the fourth industrial revolution (4IR). The revolution impacts and advances mechanical engineering where most of the production processes occur. IMECHE (2022) defines "Mechanical engineering is a multifaceted discipline that involves the teaching, practice, and guidance of others in the development and application of scientific principles to mechanical systems. Mechanical engineering encompasses the ability to solve problems that provide and optimize safe, sustainable and ethical solutions for the design, production and operation of devices, machines, structures, processes and systems with mechanical elements. Mechanical engineering often overlaps and/or combines with other engineering technologies to create multidisciplinary projects/solutions."

Alternatively, mechanical engineering is a discipline that deals with problem-solving processes/techniques from design to manufacture to marketing of a service/object. In short, it is the study of objects and systems in motion. It is the oldest and most comprehensive of the engineering disciplines. It is one of the most important drivers of economic development and the industrial agenda of any country. Mechanical engineers research, design, develop, build and test mechanical and thermal devices, including tools, motors and machines. Mechanical engineers evaluate problems to determine how mechanical devices could help solve the problem, design solutions, test feasibility and implement a workable solution.

In the US, employment of mechanical engineers is projected to grow by seven per cent between 2020 and 2030, about as fast as the average for all occupations. Over the course of the decade, several new jobs for mechanical engineers will be advertised on average each year. Many of these vacancies are expected to occur as workers move to other occupations or leave the profession, e.g. through retirement (Department of Defence, US, 2022).

The role of industrial development, which is greatly supported by the discipline of engineering, in economic growth is well known. The industrial sector facilitates the development of science and technology that promote industrial modernisation and the process of the industrialization agenda, the efficient use of resources and the reduction of unemployment. It promotes participation in international trade, which is the largest contributor to GDP. The East African Community (EAC) highlights the importance of the industrial sector as follows: "The industrial sector has the potential to make an important contribution to the economy by creating jobs, promoting the development of other sectors such as agriculture and services, increasing foreign exchange earnings and modernising people's lives" (EAC, 2022).

INDUSTRIAL REVOLUTION

The Industrial Revolution is a transition in production processes that changed the social, economic and political landscape of the world. It took place in the field of mechanical engineering. As a result, several other professions emerged.

Stages of Industrial Revolution

Table 1 gives an overview of the various industrial revolutions from the agricultural economy through the first to the fourth industrial revolution:

Table 1: Stages of Industrial revolutions

Stage	Main Developments	Impact on Mechanical Engineering	Other Professions that partly take the tasks of Mechanical Engineering
Agrarian Developments	i. Land as the main factor of production ii. Domestication of animals iii. Seed collection and planting iv. Production of iron tools for agriculture	Early agricultural mechanisation including blacksmithing	Growth of agriculture as a distinct sector

Stage	Main Developments	Impact on Mechanical Engineering	Other Professions that partly take the tasks of Mechanical Engineering
	v. Muscles (of humans and animals) were the main source of energy		
First Industrial Development (mechanization)	The law of conservation of energy was known. Coal was the main source of energy. Steam engines converted heat into kinetic energy	Creation devices and machines mechanised production. This transition meant moving from artisanal to mechanised production methods.	Various other technologies emerged, such as electrical and chemical engineering. The main issue was energy conversion.
Second Industrial Development (*Technological Revolution)* (Mass production)	Rapid scientific discovery, standardisation, mass production and industrialisation	Development of production management as a branch of mechanical engineering.	Management in business administration areas such as accounting, marketing, production management
Third Industrial Development (*Digital Revolution*) (computer and automation)	A changeover to digital technologies took place	computer-based systems such as numerically controlled/computer-aided design/computer-aided manufacturing came on the scene	Information systems/information technology and its sub-sectors emerged
Fourth Industrial Development (cyber physical systems)	Fusion of physical/digital/biological aspects in products and services. Digitization of products and services, emergence of digital business models and customer access.	Blurring among various professions	Discussed in detail in Section **Error! Reference source not found.**.

Source: Edited from Schwab (2018)

Schwab (2018) defines the 4IR as the fusion of physical (such as 3D printing, robotics, new nano-level materials), digital (artificial intelligence, blockchain technology, Internet of Things) and biological (such as biomedical engineering, biotechnology and related technologies) aspects. The 4IR builds on the third revolution. Take as an example the development of the internet, from the early days of the internet to the emergence of social networks and the internet of things. The 4IR offers both opportunities and challenges for mechanical engineers. Opportunities include higher quality products and easier customisation.

Prototyping and testing can be simplified as the time to market for a product is significantly reduced. Data is available to speed up the design, development and evaluation of new products and services.

Technologies in the Fourth Industrial Revolution

Error! Reference source not found. summarises the ideas about the development of 4IR and its impact on the mechanical engineering field. The table shows that mechanical engineering is changing a lot. To remain relevant, the profession must adapt to the developments that occur.

Table 2 illustrates that mechanical engineering of the future will shift from mechanical systems to information systems, ranging from idea generation to design, development, testing and marketing of products/services. In-depth knowledge of information systems would increase efficiency and accuracy. The IoT works with devices, with mechanical engineers working remotely yet able to identify and potentially solve common problems and make improvements. In addition, the table shows the growing importance of biology for mechanical engineering.

In the last two sections, it is clear that mechanical engineering has always represented a constant process of change, adaptation and improvement (van Geerenstein, 2022). Since the introduction of the steam engine (First Industrial Revolution), the first electrical machines with assembly line production based on the division of labour (Second Industrial Revolution), the use of IT and the associated automation (Third Industrial Revolution) or now with the intelligent and networked digital factory (4IR, Industry 4.0), mechanical engineering has perhaps been an important driver and addressee of change, because production technology is first and foremost mechanical engineering. Meanwhile, mechanical engineering is at the forefront of a new era in industry. Basically, almost all the changes of the industrial revolution are primarily due to mechanical engineering. Southeast Asia's economic growth is probably primarily due to industrial development. No other industry is currently investing more than mechanical engineering in digital technologies (van Geerenstein, 2022).

IMPACT OF 4IR IN MECHANICAL ENGINEERING PROFESSION

Although the consensus is that all occupations are affected by 4IR, only mechanical engineering is considered in this paper. Notably, one of the impacts will be routine, predictable physical and cognitive tasks such as office administration, production, transportation, and food preparation would disappear from the labour market. In this regard, there are tasks that 4IR will replace in mechanical engineering industry.

Operational Efficiency

4IR have introduced disruptive digital technologies that can help overcome traditional barriers to operations management (Luz Tortorella *et al.*, 2022; Bu *et al.*, 2022; Jengwa and Pellissier, 2022). All the technologies listed in Table 2 will improve operational efficiency throughout the machinery chain of events. As information is readily available, backward, internal and forward linkages are possible, such as enterprise resource planning (Balon *et al.*, 2022; Ghode *et al.*, 2022). Finally, operational excellence performance improves revenue, profits and return on investment (Jengwa and Pellissier, 2022).

Learning and Learning to Learn

Mechanical engineering is an evolving profession that constantly requires skill development to keep the pace with the ever-growing demands of the industry and labour market. Research shows that skill requirements are constantly changing (Dec *et al.*, 2022; Swart and Havenga, 2022). The generic skills for 4IR have been identified as "communication skills, leadership skills, critical thinking skills, problem solving skills, creativity skills, digital skills, adaptive skills, management skills and emotional intelligence"

(Kamaruzaman *et al.*, 2022). Table 3 defines these 4IR skills.

The World Economic Forum estimated in 2020 that of the top 10 emerging occupations that will create 133 million jobs in 2022, six are partly related to mechanical engineering, while of the 10 declining occupations that could destroy 75 million jobs, four are partly mechanical engineering related (World Economic Forum**, 2020.**

Table 2: Technologies in the 4IR and their impact on Mechanical Engineering

Technology and its Definition	What does it mean to mechanical engineering?
The Internet of Things (IoT) is a system of interconnected devices/objects/animals/humans that are tagged with unique identifiers and can transmit data over a network without requiring human-to-human or human-to-computer interaction.	The IoT helps monitor and improve overall business processes, increases employee productivity, integrates various business processes, improves business operations and even generates more revenue. According to a study by Redline Research, "the number of IoT devices online will reach 75 billion by 2025. This means that the future mechanical engineer must be prepared for a new era of simulations and integrated design processes, both of which will streamline workflows" " (Redline, 2022).
Nanotechnology enables the management/handling of materials at the smallest scale in development and manufacturing.	There are several opportunities, including the production of stronger composites (lighter, stronger and better materials such as carbon fibres in aircraft and electronic materials), and biomedical devices (Rajput *et al.*, 2022; Farhan *et al.*, 2022).
Biotechnology is an applied science that uses biology (living organisms and their derivatives) to produce products and processes and then apply them in various fields.	Some of the basic areas are genetic engineering. Since biotechnology is largely a combination of biology and engineering, there are a variety of applications in bioreactors, biofuel production, biorobotics, genetic engineering and other areas. The number of mechanical engineers in modern hospitals will increase significantly (Beitler *et al.*, 2022; Andhare and Onkar, 2022).
Big Data analytics uses advanced analytical techniques to understand the vast amount of information generated. Analytics uncovers hidden patterns, predicts trends, makes correlations between data elements, measures customer opinions and provides business intelligence solutions. This can be the case in both structured and unstructured situations, and with batch or streaming data.	Big Data analytics improve cost reduction, decision-making processes, new product development and marketing, while reducing the risk of product rejection and providing efficient business opportunities
Blockchain technology is a shared, distributed and decentralised immutable and constantly growing database that records and tracks tangible and intangible transactions in a business network. Cryptocurrency is one of the products of this technology.	Blockchain technology creates added value for businesses. It authenticates digital information and the changes recorded during the process and facilitates the exchange of data between objects from multiple global providers. The result is greater system efficiency and better performance monitoring with better energy management. Cryptographic mechanisms ensure secure

Technology and its Definition	What does it mean to mechanical engineering?
	communication between devices and logs of data flows are kept as a permanent record of who, what, when and where data was accessed. This improves quality assurance. Blockchain technology can help identify the origin of raw materials and prevent counterfeiting.
Artificial intelligence is the simulation of human intelligence processes such as visual perception, speech recognition, decision-making, and translation between languages by machines, especially computer systems.	Specific applications of Artificial Intelligence (AI) include expert systems, natural language processing, speech recognition, and machine vision. It is also the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. Robots perform manufacturing and control tasks, expert systems mimic human behaviour, while neural network algorithms imitate the human brain in making complex decisions.
3D printing is a process in which three-dimensional physical objects are produced from a digital file by applying many thin layers of a material one after the other.	3D printing enables optimised engineering designs, much shorter lead times, animation development and improves on-site production of spare parts (you order the digital file of the spare part and print it, not the spare part).

Source: Summarized from Schwab (2018)

Table 3: Skills for 21st Century

Skill	Definition to Mechanical Engineering
Creativity	"The ability to think outside the box." To what extent can a mechanical engineer develop ideas and arguments? What do mechanical engineers see outside the box when they see several road accidents in Tanzania? Is it primarily a mechanical engineering problem?
Critical thinking	"Logical and well-reasoned conclusions." Critical thinking is associated with eloquence, originality, elaboration, flexibility and analogising things so that a complex problem is seen as a simple problem (Wright *et al.*, 2022).
Collaboration	"A willingness to listen, learn and collaborate with others to achieve a common goal." Can mechanical engineers work with doctors to solve medical problems? Can mechanical engineers help farmers improve food production?
Communication	"All the technical knowledge and skill in the world is not worth much if you cannot get your point across in a respectful and coherent way." Do mechanical engineers have good language skills? Can mechanical engineers convince your boss to increase your research budget?
Information literacy	"Separate fact from fiction." Will the COVID 19 vaccine turn us all into zombies?
Adaptability	"You need to be able to work remotely as well as in the office, independently and as part of a team." Do mechanical engineers have information technology that enables them to work remotely? A degree of independence or just copy-and-paste types?
Leadership	"This includes humility, decisiveness and leadership skills." Can mechanical engineers make decisions? Do they use their staff's expertise wisely or do they just come across as a threat? Can they predict well?
Social skills	"Self-awareness, self-regulation and empathy." Do mechanical engineers have social capital?
Productivity	"Distinguish between being busy and being productive." Do mechanical engineers know the difference between being busy and being productive?

Shifting Division of Labour between Humans, Machines, and Algorithms

Occupations that have either a high concentration of routine work or increased risk will see the greatest shift to low-wage service employment in the 4IR era as the division of labour between humans, machines and algorithms for these tasks blurs. As expert systems and neural networks mature, machines and algorithms will take over more than three-quarters of all tasks (World Economic Forum, 2020). Even tasks that require a lot of human interaction could be shifted to computers, especially in the areas of communication and management.

Innovation

In the era of 4IR, the rise of machine intelligence and IoT in systems seems to be fueling a highly individualized and dynamically changing market where more and more customers demand personalized or customised products (Ming *et al.*, 2022; Soni *et al.*, 2022). Reshaping the world through innovation is important for survival (Peerally *et al.*, 2022; Nimawat and Gidwani, 2022). The findings of this review strongly indicate the importance of employing innovative skills in Mechanical engineering industry to remain relevant in the labor market.

INDUSTRIES FOR BETTER FUTURE OF MECHANICAL ENGINEERING

There are several technologies that require the growth of mechanical engineering. This paper discusses some of them as elaborated in this section.

Investments in IoT

IoT Analytics (2022) estimates the growth of IoT to be exponential in past decades as shown in **Error! Reference source not found.**. The technological advancement promotes more use and application of internet in many tasks and activities. Likewise, it is important for mechanical engineers to link their developments to the IoT. It is better if all designs incorporate the IoT from manufacturing to monitoring to maintenance.

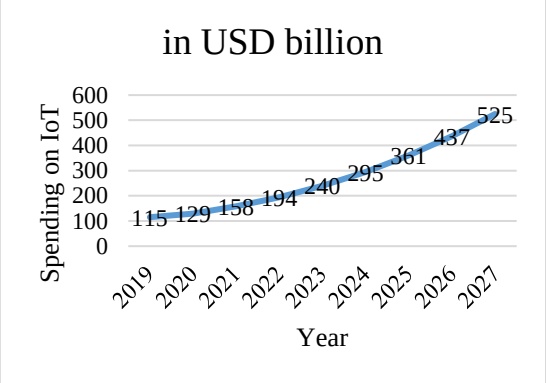

Figure 1: Growth of IoT from 2021 to 2027 (up to March 2022 actual data while beyond are predications), (IoT Analytics, 2022)

Electric Vehicles

It is believed that the future of vehicles will be electric. The global electric vehicle market was estimated at USD 163.01 billion in 2020 and is expected to reach USD 823.75 billion by 2030, with an average growth rate of 18.2% between 2021 and 2030 (PR Newswire, 2022). The traditional internal combustion engine will gradually be replaced by battery-powered systems (PR Newswire, 2022). This development challenges engineers to invest in mechatronics to support the new electric systems. As vehicle manufacturing becomes increasingly automated, mechanical engineers will play a central role in the development of robots and assembly lines. As car prices fall, demand for cars will rise. Nanotechnology would redefine the way cars are repaired.

Self-driving cars would become the norm rather than the exception (Gantsho, 2022; Kaszas and Roberts, 2022). Many engineers would be needed for newly designed automated transport systems. Therefore, a good relationship with civil and traffic engineers is needed.

Nano Engineering

The global nanotechnology market is expected to grow from USD 1.76 billion in 2020 to USD 33.36 billion in 2030 in electronics, energy, chemicals and manufacturing, aerospace, healthcare and others, with strong growth in electronics and healthcare (Allied Market Research, 2022). Nano-engineering is increasing the importance of materials science in engineering tools and machinery. Composite materials and storage systems for renewable energy would be a good career field for mechanical engineering.

Bio-mechatronics

Almost all industries today require mechatronics. There are currently an estimated 132,500 mechatronics engineers in the United States of America. The job market for mechatronics engineers is expected to grow by 6.4% between 2016 and 2026 (Jadon, 2022). Mechatronics engineers are needed to automate existing production processes (efficiency), analyse the profitability of new and existing equipment (problem solving), perform simulations and modelling of engineering systems (design), integrate systems that improve performance and production (operation), design and build new products, and solve complex engineering problems using mechanical, electronic and computer technologies. There will be close collaboration between mechanical engineering and medicine to develop bio-mechatronics, which will become increasingly important. This field aims to merge body and machine (4IR means the fusion of physical, biological and digital aspects in manufacturing) and involves the design and testing of complex and intricate device architectures that mimic the structure of the body's own musculoskeletal system by developing mechanical sensors, controls and actuators for biomedical devices used in prosthetics and miniature medical implants. Accident victims who can no longer walk, even with the help of today's medical technology, will be able to walk again. This will also be true for other sensory organs. Biomedical devices will encompass a wide range of products with varying complexity and purpose.

Manufacturing

Manufacturing is one of the oldest areas of technology and is constantly evolving. Increasing production efficiency while minimising operating costs is driving demand for new and innovative technologies. Automation and robotics remain essential to keep pace with consumer demand while maximising profits. Robotics will inevitably increase. Mechanical engineers and designers are needed to develop and manage robots and automation solutions.

Energy Solutions

While fossil fuels will be the main source of energy for the foreseeable future, green energy will increase. New energy solutions are needed to protect the environment. The need for renewable energy mechanical engineers and smart product designers will increase. Cheap electricity from renewable sources could provide 65 per cent of the world's total electricity supply by 2030. This could decarbonise 90 per cent of the power sector by 2050, helping to massively

reduce carbon emissions and mitigate climate change (UN, 2022). Moreover, every dollar invested in renewable energy creates three times more jobs than in the fossil fuel industry (UN, 2022).

CONCLUSION

Mechanical engineering will continue to serve as an engine for economic development. Technological upheavals will continue. This paper identifies several issues that should be given attention in mechanical engineering. This revolution will be unstoppable and all professions will be affected (either negatively or positively). The article contains some concluding remarks.

The World is in an Era of 4IR

The 4IR will overturn many common notions of mechanical engineering and possibly replace conventional production processes to make them more automated. The 4IR will be cost-efficient and environmentally friendly, especially in the area of electric cars and energy solutions. The economy (a labour market that relies heavily on temporary and part-time jobs filled by independent contractors and freelancers, rather than full-time permanent employees) will permeate all countries.

Its Impact will be felt by all Professions

Based on the literature review, several 4IR technologies have emerged that will shape the future of mechanical engineering. The technologies will be easier to learn and somewhat easier to implement (Mogas *et al.*, 2022; Gajdzik and Wolniak, 2022). The degree of success will depend on the knowledge available.

Future Scope of Mechanical Engineering cannot be properly Estimated

The volume and demand for mechanical engineers is expected to increase in the future. However, the complexity of the tasks and the distribution of what will be done by machines and what by humans is not yet clear. The article has shown that mechanical engineers to be employed in the future must also have extensive knowledge of biology and information systems.

RECOMMENDATIONS

Appropriate actors need to promote continuous learning, invest in retraining incumbent workers and facilitate smoother adjustments.

Merging the Mechanical and the Digital Technologies

Mechanical engineering is the most widespread engineering discipline and is in a unique position to benefit from the digital revolution, more so than other engineering professions. The 4IR digital technologies that need to be immediately incorporated into the mechanical engineering curriculum include ubiquitous networked sensors including the Internet of Things, virtual and augmented reality, additive manufacturing including 3D printing, blockchain and distributed ledger technology (including cryptocurrencies), and new computing technologies including quantum computing. This argument does not downplay the importance of other technologies such as computer-aided design/computer-aided manufacturing.

Investing on Skills on Automation and Smart Systems with the Use of IoT

Considering that the number of connected things will reach 50 billion

within the next five years and will continue to grow exponentially (Salih *et al.*, 2022), the connected industry is the future. This development will make it easier to bring design and production to market, to control and ensure quality, and to detect production bottlenecks.

The IoT between industrial devices, sensors, machines and other instruments enhances machine-to-machine communication and machine learning to improve the efficiency and accuracy of a variety of engineering processes, such as: lower costs with higher productivity and better customer experience.

The current job market requires engineers to stay up to date, which also affects the curricula. Therefore, it is the duty of faculties to equip students so that they can successfully prepare for their future roles. It is important to make engineering relevant: even if some jobs disappear, almost twice as many new ones are created (World Economic Forum, 2020).

Mechanical Engineering with Knowledge on Green Engineering

Since most human activities that impact climate change originate in industry, mechanical engineers can contribute by designing them accordingly. Consequently, climate change initiatives such as smart city development will be the rule rather than the exception. To be successful in the future, mechanical engineers must embrace green technologies. Any green technology innovation that reduces pollution, protects natural resources, promotes sustainability, reduces energy consumption and minimises risks to human health and the environment without compromising economy and efficiency can find an immediate market.

Take it one step at a time

Some changes are emerging in both mechanical engineering and 4IR. It would be impossible to go into all the developments, as several professions have to work together here. The developments described in this article paint a clear picture of where mechanical engineering is heading. These skills cannot all be acquired at once, but they still need to be learned. For example, the professions can agree on which skills should be taught in universities, which should be taught in conferences/seminars and which should be available online. It is important that engineers gradually learn to cope with changes in the industry. The areas that are not possible today will be able to be done by machines.

Soft Skills not to be Ignored

All mechanical engineering curricula must therefore insist on the soft skills listed in **Error! Reference source not found.**.

REFERENCES

Allied Market Research. (2022). Nanotechnology Market by type (nanosensor and nanodevices) and application*: Global* Opportunity *Analysis and Trends 2020 - 2030*. Retrieved from https://www.alliedmarketresearch.com/nanotechnology-market

Andhare, A., and Onkar, A. (2022). Human factors, ergonomic considerations and hospital bed designs: a review. *International Journal of Human* Factors *and Ergonomics*, **9**(1): 47-72.

Balon, B., Kalinowski, K., and Paprocka, I. (2022). Application of Blockchain Technology in Production Scheduling and Management of Human Resources Competencies. *Sensors*, **22**(8): 2844.

Beitler, B. G., Abraham, P. F., Glennon, A. R., Tommasini, S. M., Lattanza, L. L., Morris, J. M., and Wiznia, D. H. (2022). Interpretation of regulatory factors for

3D printing at hospitals and medical centers, or at the point of care. *3D Printing in Medicine*, **8**(1): 1-7.

Bu, S., Jeong, U. A., and Koh, J. (2022). Robotic process automation: A new enabler for digital transformation and operational excellence. *Business Communication Research and Practice*, **5**(1): 29-35. doi:doi.org/10.22682/bcrp.2022.5.1.29

Dec, G., Stadnicka, D., Paśko, Ł., Mądziel, M., Figliè, R., Mazzei, D., Tyrovolas, M., Stylios, C., Navarro, J., Solé-Beteta, X. (2022). Role of Academics in Transferring Knowledge and Skills on Artificial Intelligence, Internet of Things and Edge Computing. *Sensors*, **22**(7): 2496. doi:doi.org/10.3390/s22072496

Department of Defence, US. (2022). Mechanical Engineers. Retrieved from https://myfuture.com/career/mechanical-engineers

EAC. (2022). Industrialisation and SME Development. Retrieved from https://www.eac.int/industry#:~:text=The%20industrial%20sector%20has%20the,modernising%20the%20lives%20of%20people.

Farhan, M., Mastura, M. T., Ansari, S. P., Azeem, M., and Sapuan, S. M. (2022). Advanced Potential Hybrid Biocomposites in Aerospace Applications: A Comprehensive Review. *Advanced Composites in Aerospace Engineering Applications*, 127-148.

Gajdzik, B., and Wolniak, R. (2022). Smart Production Workers in Terms of Creativity and Innovation: The Implication for Open Innovation. *Journal of Open* Innovation*: Technology, Market, and Complexity*, **8**(2): 68.

Gantsho, L. (2022). God does not play dice *but* self-driving cars should. *AI and Ethics*, **2**(1): 177-184.

Ghode, D. J., Jain, R., and Soni, G. (2022). Challenges of Adoption of Blockchain Technology in Supply Chain: An Overview. *Recent Advances in Industrial Production*, 257-165.

IMECHE. (2022, 12 1). *Definition of mechanical engeneering.* Retrieved from IMECHE: https://www.imeche.org/membership-registration/become-a-member/definition-of-mechanical-engineering

IoTAnalytics. (2022). *Global IoT market size grew 22% in 2021 — these 16 factors affect the growth trajectory to 2027.* Retrieved from https://iot-analytics.com/

Jadon, V. K. (2022). *The growing scope of Mechatronics Engineering.* Retrieved from https://www.chitkara.edu.in/

Jengwa, E., and Pellissier, R. (2022). An operational excellence strategy implementation model for growth in a volatile, uncertain, complex, and ambiguous environment. *Acta Commercii*, **22**(1): 11. doi:doi.org/10.4102/ac.v22i1.960

Kamaruzaman, F. M., Hamid, R., Mutalib, A. A., and Rasul, M. S. (2022). Determination of 4IR Generic Skills Constructs for Engineering Graduates. *Journal of* Positive *School Psychology*, **6**(3): 243-257. Retrieved from https://journalppw.com/index.php/jpsp/article/view/1364

Kaszas, D., and Roberts, A. C. (2022). Comfort with varying levels of human supervision in self-driving cars: Determining factors in Europe. *International Journal of Transportation Science and Technology*. doi:https://doi.org/10.1016/j.ijtst.2022.08.001

Luz Tortorella, G., Cauchick-Miguel, P. A., Li, W., Staines, J., and McFarlane, D. (2022). What does operational excellence mean in the Fourth Industrial Revolution era? *International Journal of Production Research*, **60**(9): 2901-2917. doi:doi.org/10.1080/00207543.2021.1905903

Ming, Z., Nellippallil, A. B., Wang, R., Allen, J. K., Wang, G., Yan, Y., and Mistree, F. (2022). Requirements and *Architecture* of the Decision Support Platform for Design Engineering 4.0. In *Architecting A Knowledge-Based*

Platform for Design Engineering 4.0 (pp. 1-22). Cham: Springer.

Mogas, J., Palau, R., Fuentes, M., and Cebrián, G. (2022). Smart schools on the way: How school principals from Catalonia approach the future of education within the fourth industrial revolution. *Learning Environments Research,* **25**(3): 875-893.

Nimawat, D., and Gidwani, B. D. (2022). An overview of industry 4.0 in manufacturing industries. *International Journal of Industrial* and *Systems Engineering,* **40**(4): 415-454. Retrieved from https://www.inderscienceonline.com/doi/abs/10.1504/IJISE.2022.122820

Peerally, J. A., Santiago, F., De Fuentes, C., and Moghavvemi, S. (2022). Towards a firm-level technological capability framework to endorse and actualize the Fourth Industrial Revolution in developing countries. *Research Policy*, **51**(10): 104563. doi:doi.org/10.1016/j.respol.2022.104563

PR Newswire. (2022). Retrieved from Electric Vehicle Market To Reach USD 823.75 Billion By 2030 Registering A CAGR Of 18.2% - Valuates Reports: https://www.prnewswire.com/

Rajput, A., Shukla, S. K., Thakur, N., Debnath, A., and Mangla, B. (2022). Advanced Polymeric Materials for Aerospace Applications. *Aerospace Polymeric Materials*, 117-136.

Redline. (2022). What to expect for the future of mechanical engineering? *What to expect for the future of mechanical engineering?* Retrieved from https://www.redlinegroup.com/news/what-to-expect-for-the-future-of-mechanical-engineering-16129558364

Salih, K. O., Rashid, T. A., Radovanovic, D., and Bacanin, N. (2022). A comprehensive survey on the Internet of Things with the industrial marketplace. *Sensors*, **22**(3): 730. doi:https://doi.org/10.3390/s22030730

Schwab, K. (2018). Shaping the future of the fourth industrial revolution: A guide to building a better world. World Economic forum.

Soni, G., Kumar, S., Mahto, R. V., Mangla, S. K., Mittal, M. L., and Lim, W. M. (2022). A decision-making framework for Industry 4.0 technology implementation: The case of FinTech and sustainable supply chain finance for SMEs. *Technological Forecasting and Social Change*, **180**: 121686. doi:doi.org/10.1016/j.techfore.2022.121686

Swart, A. J., and Havenga, M. (2022). Identifying learning strategies among first-year engineering students. *VOLT: Jurnal Ilmiah Pendidikan Teknik Elektro,* **7**(1): 1-12. doi:dx.doi.org/10.30870/volt.v7i1.11562

UN. (2022). *Renewable energy – powering a safer future.* Retrieved from https://www.un.org/en/climatechange/raising-ambition/renewable-energy

van Geerenstein, D. (2022). Mechanical Engineering and Industry 4.0. In Handbook *Industry 4.0* (pp. 535-555). Berlin, Heidelberg: Springer.

World Economic Forum. (2020). *The* future *of jobs report 2020.* Geneva: World Economic Forum.

Wright, K., Slaboch, P. E., and Jamshidi, R. (*2022*). Technical writing improvements through engineering lab courses. International Journal of Mechanical Engineering Education, **50**(1): 120-134. doi:https://doi.org/10.1177/0306419020939621