SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

Industry 5.0: Exploring the Role of Human-Centric Design in Transformative Learning Factories

Tesi di Laurea Magistrale in Management Engineering

Author: Mustafa Issa Ali Dungus

Student ID: 10701909

Advisor: Prof. Monica Rossi

Co-advisors: Maria Rossetti

Academic Year: 2023-24

Abstract

The emergence of Industry 5.0, which focuses on the symbiotic relationship between humans and robots in the manufacturing sector, is a drastic shift in paradigms. This study delves into the human-cantered aspect of Industry 5.0, particularly through evaluations of immersive learning conducted within what are known as learning factories. Participants are subjected to belief, enjoyment, and self-belief assessments before and during their interactions with cooperative robots and virtual/augmented reality stressing the importance of experiential learning that uncovers details missed by traditional knowledge surveys. Pre- and post-experience reviews indicate noticeable changes in stakeholders' perception towards safety, empowerment, inclusivity as well as ease-of-use VR/AR technologies offer showing how different these emerging technologies consider various user needs based on such simple but effective methods like observation within users' work contexts.

The changes illustrate an approach to immersive learning that results in a confident, diverse and technology adept workforce. The investigation takes participant diversity into account by looking at demographics along with the organizations and jobs of those involved— this comprehensive contextualization allows us to see how these different aspects impact the engagement towards emerging manufacturing concepts. In simple terms, this study widens the horizon of knowledge in Industry 5.0, providing more details on how transformative an immersive learning environment can be. It shows that such active involvement can change attitudes; promote digital literacy shift and facilitate towards flexibility as well as inclusivity for manufacturing.

The results of this study could be an important resource for companies that are able to develop, produce and operate products in the human-cantered way in this era when Industry 5.0 starts replacing the traditional manufacturing process with new roles and rules.

Keywords: Industry 5.0, Immersive Learning, Human-Cantered Manufacturing, Cooperative Robots, Virtual/Augmented Reality (VR/AR) Technologies

Sommario

L'emergere dell'Industria 5.0, che si concentra sulla relazione simbiotica tra hu-mans e robot nel settore manifatturiero, è un drastico cambiamento di paradigma. Questo studio approfondisce l'aspetto umano-cantered dell'Industria 5.0, in particolare attraverso valutazioni di apprendimento immersivo condotte all'interno di quelle che sono note come fabbriche di apprendimento. I partecipanti sono sottoposti a valutazioni di credenze, godimento e fiducia in se stessi prima e durante le loro interazioni con robot cooperativi e realtà virtuale/ aumentata, sottolineando l'importanza dell'apprendimento esperienziale che scopre dettagli mancanti dalle indagini sulla conoscenza tradizionale. Le revisioni pre e post-esperienza indicano cambiamenti evidenti nella percezione delle parti interessate verso la sicurezza, l'empowerment, l'inclusività e la facilità d'uso delle tecnologie VR/ARmostrare come queste tecnologie emergenti considerino diverse esigenze degli utenti basate su metodi così semplici ma efficaci come l'osservazione all'interno dei contesti di lavoro degli utenti.

I cambiamenti illustrano un approccio all'apprendimento immersivo che si traduce in una forza lavoro fiduciosa, diversificata e dotata di tecnologia. L'indagine tiene conto della diversità dei partecipanti esaminando la demografia insieme alle organizzazioni e ai posti di lavoro di coloro che sono coinvoltiLa tualizzazione ci permette di vedere come questi diversi aspetti influenzano l'impegno verso i concetti di produzione emergenti. In termini semplici, questo studio allarga l'orizzonte della conoscenza nell'Industria 5.0, fornendo maggiori dettagli su come può essere trasformativo un ambiente di apprendimento immersivo. Ciò dimostra che un tale coinvolgimento attivo può cambiare gli atteggiamenti; promuovere l'alfabetizzazione digitale - spostarsi e facilitare - verso la flessibilità e l'inclusività per la produzione.

I risultati di questo studio potrebbero essere una risorsa importante per le aziende che sono in grado di sviluppare, produrre e gestire prodotti in modo umano-cantered in questo periodo in cui l'Industria 5.0 inizia a sostituire il tradizionale processo di produzione con nuovi ruoli e regole.

Parole chiave: Industria 5.0, Apprendimento Immersivo, Manifattura Human-Centered, Robot Cooperativi, Tecnologie VR/AR

Table of Contents

List Of Figures

List Of Tables

1 OVERVIEW

The transformation from industry 4.0 to industry 5.0 truly involves a paradigm shift while focusing on the manufacturing sector human-centric manufacturing industry 4.0 mainly emphasized the integration of technologies such as cyber-physical systems io t big data analytics artificial intelligence and robotics [1]. Industry 5.0 will now further emphasize blending human creativity expertise and intuition within the ambit of these advanced technologies this new paradigm promotes a harmonious relationship of collaboration and cooperation with humans and machines for a resilient sustainable and inclusive manufacturing ecosystem instrumental to this industry 5.0 are definitely the transformative learning factories which seamlessly integrate theoretical knowledge across all domains of learning with hands-on experiential [5]. these innovative educational settings imitate real industrial environments in which both students and employees can learn and practice allowing for experience problem solving and constant advancement through the creation of human centred design and advanced manufacturing technology awareness learning factories further prepare individuals for the industry 5.0 era [8].

1.1 Industry 4.0 to Industry 5.0 Transition

The manufacturing industry has gone through major changes over the past few centuries that it has existed. In this time, there have been several industrial revolutions: the second one used electricity for mass production while the first used water and steam power to mechanize manufacture. The third brought in information technology and electronics that initiated automation systems after establishing them. Industry 4.0, as the most recent revolution, sees artificial intelligence (AI) working hand in hand with cyber-physical systems like the internet of things (IoT)— ushering smart factories into a new era where connectivity is enhanced; data analytics are more sophisticated, and more processes are automated [1].

The main areas of the industry 4.0discussions have been around efficiency improvements and technological advancements, despite all breakthroughs/mud advancements. However, with the advancing of manufacturing, people have come to know of its importance in industrial process once again. That, then, birthed Industry 5.0 — an era where sustainability and human-centric innovation reign supreme alongside a symbiotic relationship between people and robots. The fusion of human well-being and technical acceleration will serve as Industry 5.0 to foster a safer, more equitable place to work, and more adaptive production environments [6].

1.2 Definition and Significance of Industry 5.0

In simpler terms, Industry 5.0 is more about changing the mindset to take human-robot collaboration and human-cantered design to a whole new level. Industry 5.0 pivots towards human arm in production, emphasizing creativity, competences and well-being as opposed to the automation and efficiency that its predecessor was all about [4]. In the next industrial revolution, it is likely to be supplemented by modern technologies that will support human abilities instead of replacing them, such as virtual reality, augmented reality, and cobots (collaborative robots) [5].

In any case, the fifth industrial revolution that we are talking about here is a significant one in the world today because it seeks to deal with major challenges in modern production such as the need for greater sustainability, flexibility and adaption. It hopes to raise job contentment, security and inclusive nature through enhancing good relations between people and machines to enhance productivity. Perhaps what will result from this approach cantered on human beings is a resilient, imaginative manufacturing system that can respond more easily to changing requirements of the global market [6].

1.3 Human-Centric Manufacturing's (HCM) Importance in Industry 5.0

Human-Centric Manufacturing (HCM) is a fundamental component of Industry 5.0. HCM is built on the premise that human participation in manufacturing processes is highly critical. In industrial systems, human involvement, empowerment and well-being are given priority, hence the creation of HCM specifically for these systems [5]. The process contends that despite technology's ability to enhance output and efficiency in process execution, human insight, innovation and problem solving remain the preserve of humans themselves [8]. This makes HCM essential for industry 5.0. First, it encourages a safe workplace through use of state-of-the-art tools such as Cobots and AR/VR with an aim to empowering employees while reducing accidents risks. This makes industrial systems more accessible and adaptable to the different physical capabilities as well as experience levels within its workforce. With technology applied, this results in a more engaging and sophisticated working environment thereby increasing job satisfaction and staff retention rates. It therefore helps to narrow down the gap between labour and technology thus creating way forward for stronger/future onward industries that are sustainable [3].

1.4 Research Objective and Scope

The purpose of this study is to establish how human-centric design works in transformative learning factories with regards to Industry 5.0. This entails a comprehensive examination of the ways in which immersive learning experiences, enabled by Collaborative Robots and Virtual Reality/Augmented Reality (VR/AR) technologies, affect participants' perceptions, estimations and self-concept [1].

The following are specific objectives of this study:

1.Understanding Human-Centric design in industry 5.0

Human-centric layout in industry 5.0 focuses on people's engagement with machines rather than on humans solely interacting with other people or objects only. The purpose is to explain what human-centric design is about within the context of Industry 5.0 through emphasizing critical points that can support the fusion between technology and individuals.

2.Evaluating Effects of Collaborative Robots

Collaborative robots referred to as 'cobots' in the industry are intended for working side by side with humans towards improving productivity while ensuring safety and convenience for use by anybody. This research will therefore aim at understanding whether users' interests such as feeling safe, being empowered or even becoming comfortable when using these machines vary depending on their experience with cobots in a research factory setting.

This study will measure how people's attitudes towards cobots change before and after their interactions with them, giving insights into how they can contribute to creating human-oriented production environments.

3. Assessing the Role of Augmented and Virtual Reality

Virtual reality (VR) and augmented reality (AR) technologies provide immersive learning experiences that can augment information and engagement in complex production processes. Focusing on how these technologies affect inclusivity, usability, technological literacy and any other factor may be pertinent to this research that investigates the use of VR/AR technology in learning as contributing factors to contributory perceptions of contributors' views on inclusivity, usability, technological literacy among others. To ascertain whether VR/AR is beneficial to increase learners' confidence and proficiency needed for using advanced manufacturing technology or not, opinions from both before and after experience were compared as a possible answer to this question.

4. Evaluation of Changes in Self-Confidence

Improving the self-confidence of employees when it comes to using new technologies is an essential component of human-centered design. This study aims at comparing participants' self-assurance levels prior to participating in immersive VR/AR as well as cobot-based learning activities.

The goal is to comprehend how such technologies can help create a workforce that is more self-assured and polished and capable of thriving in the rapidly changing Industry 5.0 environment.

5. Examining the Impact of Demographics on Education

The participants in this study have a variety of demographic backgrounds, including varied ages, genders, levels of education, and positions in the community. These studies aim to investigate the ways in which contributors' engagement with human-centric design principles and immersive learning experiences with technology are influenced by these demographic characteristics. Through an understanding of the demographic factors, the study aims to provide customized guidance for becoming more powerful and inclusive in learning environments within Industry 5.0.

6. Filling up Knowledge Gaps with Applied Learning

In order to close the knowledge gap between industry 5.0's advanced technologies and conventional manufacturing methods, experiential mastery is crucial. This study aims to investigate how contributors' competence and the popularity of human-centric manufacturing standards can be enhanced through hands-on experiences with cobots and VR/AR technologies. The purpose of the analysis is to show that immersive, practical mastery is essential to equipping the workforce to meet the expectations of Industry 5.0.

7. Offering Useful Implementation Insights

Lastly, the study aims to provide useful advice and insights for applying human-centric design in learning factories. These insights, which could address skill-demanding scenarios and best practices for integrating cobots and VR/AR technologies in production training applications, will be entirely based on empirical records gathered throughout the study. The intention is to provide a road map for businesses looking to implement Industry 5.0 concepts, ensuring they can establish more technologically advanced, inclusive, and adaptable work environments.

Insight	**Description**
Skill Demand Analysis	Identifying the skills needed for effective use of cobots and VR/AR
Best Practices for Integration	Strategies for successfully integrating cobots and VR/AR into training
Employee Engagement Techniques	Methods to increase worker participation and acceptance of new technologies

Table 1. Practical Implementation Insights for Industry 5.0

This table provides practical insights and recommendations for companies looking to implement Industry 5.0 concepts in their training programs.

To better understand Industry 5.0 and factories, this research aims to examine the role that human-centric design plays. It focuses on the revolutionary potential of collaborative robots and virtual reality/augmented reality technology. Through evaluating their impact on participants' perspectives, studies, and self-assurance, this study aims to offer significant insights for enhancing more inclusive and productive industrial learning settings.

The research aims to gather and analyze information about people's experiences, observations, and interactions with Human-Centric Manufacturing (HCM) and learning about manufacturing unit activities both before and after teaching sports in a virtual cave environment. To better understand the variety of backgrounds and any variations in responses, the first questionnaire gathers demographic information such as identities, gender, age, company name and quarter, and participant responsibilities. In addition, it evaluates protection perceptions, baseline HCM familiarity, reports with collaborative robotics, and VR/AR technology familiarity. The second questionnaire assesses how the coaching activities affected participants' views and experiences, with particular attention on safety, worry levels, accessibility, simplicity, self-belief, and empowerment. By examining the impact of immersive learning opportunities on many stakeholders in the production zone, this all-encompassing approach aims to provide light on how organizational and demographic circumstances influence adherence to innovative production principles. The demographic data guarantees a detailed examination, exposing trends and differences across jobs, industry, age, and gender. This improves HCM knowledge and helps people understand how production units affect specific people.

1.5 Research Approach

1.5.1 Literature Review

Literature was extensively reviewed and covered the evolution of industrial revolutions, intrinsic values of Industry 5.0, and theoretical as well as practical perspectives associated with Learning Factories. This has presented, on one hand, a baseline understanding of the current status of the art and, on the other, also identified critical gaps which the thesis intends to fill. The literature review guaranteed familiarization with the entire trajectory of HCM as part of the emerging Industry 5.0 paradigm by combing through various academic articles, reports from industry, and case studies. That also explained how, in its final evolution, HCM requires advanced technologies to come together with human-centered approaches and underlined Learning Factories' potential for leading the modernity in industrial education and training.

1.5.2 Learning Factory Development

Literature guided the learning factory in designing a model that integrates the real and learning environments to simulate an actual industrial setting. It was envisioned as a dynamic environment that supported learning to take place both formally, informally, and non-formally, with emphasis on practical application of knowledge and solving real-world problems. For designing, it was considered the joining of collaborative robots, VR/AR technologies, and interactive modules into the creation of an immersive and hands-on educational experience. This learning factory model brought together theoretical knowledge and practical skills in an effort to bring greater understanding of HCM technologies and how they are applied within Industry 5.0.

1.5.3 Validation of the Learning Factory

The validation process of the learning factory model was conducted in different educational and industrial contexts. The feedback data were drawn from educational interventions in a digital cave environment in order to improve human-centered skills for manufacturing. Under such circumstances, everybody could try out HCM technologies in a controlled environment very close to real conditions, so experiences and perceptions could be observed. Additionally, feedback was elicited from participants and industry experts as part of the validation process. This feedback was important in fine-tuning the model with respect to relevance and effectiveness for enhancing the competencies targeted for Industry 5.0. The repetitive process during validation identified and brought out the strengths and weaknesses, hence rendering a robust and well-informed learning factory model in support of advanced manufacturing education and training.

2 Literature Review

2.1 Evolution of Industrial Revolutions

The concept of the industrial revolution has long been pivotal in shaping our understanding of economic political and social evolution over the past two centuries traditionally it has been attributed to a series of groundbreaking technological advancements originating in late eighteenth century Britain heralding an era of industrialization urbanization and societal transformation these innovations were perceived as liberating economies from the Malthusian constraints thus enabling sustained improvements in living standards moreover they set the stage for modernity by establishing new modes of work organization and societal structures demanded by technological progress and emerging energy sources [9]. Consequently the industrial revolution has been regarded as a defining moment in the history of modernization with its influence resonating globally shaping perceptions of political and military strength however contemporary perspectives acknowledge the oversimplification of the classic narrative which attributed the industrial revolution primarily to specific technological breakthroughs championed by British inventors post world war ii a shift in scholarly discourse particularly in economic history has prompted a deeper exploration of the multifaceted factors underlying sustained industrial growth [9]. this revaluation initially focused on the British context eventually expanded to comparative analyses encompassing Europe the United States and Asia challenging the notion of a singular British centric industrial revolution this recontextualization emphasizes a broader understanding of the industrial revolution as a global phenomenon less reliant on individual inventions and more rooted in broader economic and environmental transformations [9]. Consequently, traditional models of industrialization especially the catch up narrative prevalent in Japanese historiography have come under scrutiny [1]. Despite pioneering efforts by scholars such as Animoto Masayuki to unveil alternative paths of industrial development in Japan entrenched perceptions of modernity remain closely tied to the conventional industrial revolution paradigm contrary to popular belief the industrial revolution characterized by large scale mechanical innovations and urban factory systems only gained widespread recognition towards the end of the nineteenth century this delay in perception underscores the diversity of industrialization processes with Japan charting a distinct path marked by unique technical and organizational frameworks compared to the British model [18]. Consequently, reframing the narrative of Japanese history within this broader context offers new insights into global industrialization dynamics and challenges the notion of Japan s mere catch up with western industrialization.

The post World War II revaluation of the industrial revolution spurred by advancements in quantitative methodologies revealed a more nuanced understanding of economic growth dynamics [19]. Contrary to the traditional narrative of revolutionary inventions driving rapid economic expansion research indicated a more gradual and sustained process of change spanning the eighteenth and nineteenth centuries this dethroning of the industrial revolution highlights longer term structural shifts and incremental innovations as crucial precursors to the eventual acceleration of growth in the mid nineteenth century in essence the industrial revolution emerges as a protracted multifaceted process encompassing stages of incubation and subsequent acceleration challenging simplistic notions of singular technological breakthroughs [19]. This reframing underscores the importance of holistic and longitudinal perspectives in analysing industrial transformations and their societal implications.

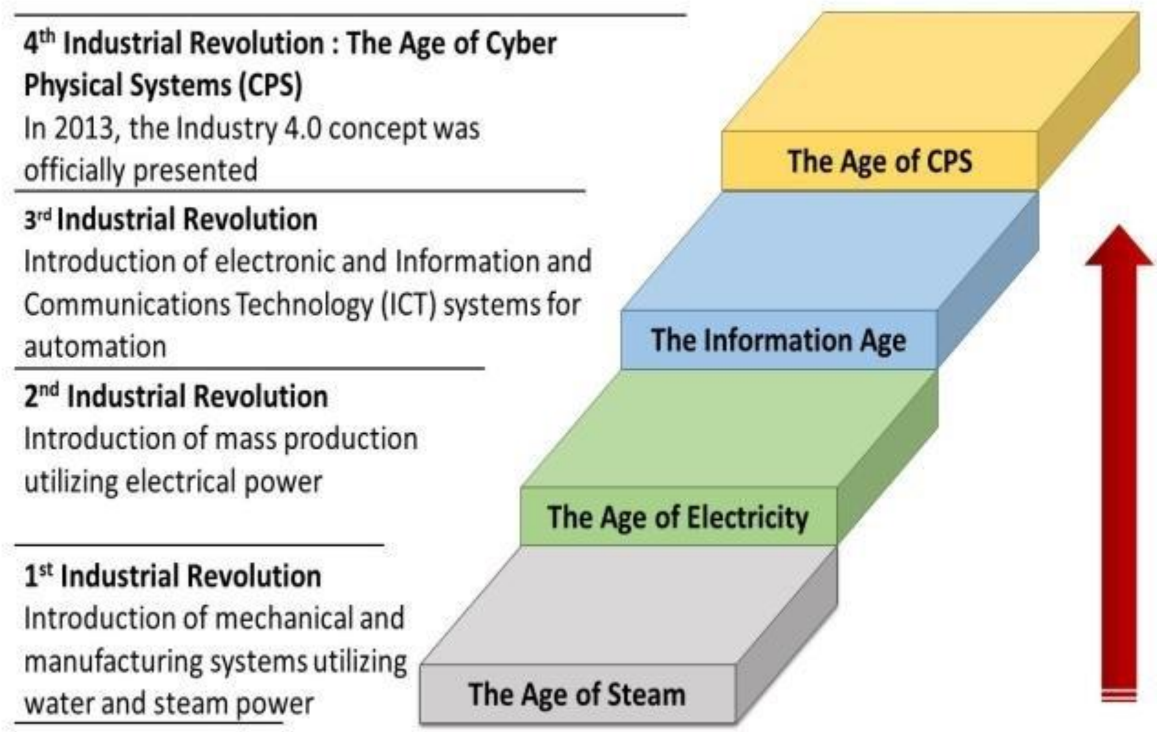

Figure 1. The Evolution of the Industrial Revolutions [23]

The first industrial revolution began in Britain in the late 1700s it was a major transition from hand production and craftsmanship to machine-based manufacture central to this was the coal fired steam engine a new invention offering a previously unseen and vast reliable and powerful source of energy this in turn radically changed industrial production enabling factories to be created and steam used to power machinery previously most industry had relied on renewable energy such as wind or water key industries during this period of productivity gains included textiles glass production coal mining and steam transport [21].

The most important invention of all was mechanical cotton spinning a new form of technology that transformed the textile industry the productivity gains from this were enormous output increased by a thousandfold in just two generations and a hundredfold in just one generation this explosive growth in efficiency and output showed how much mechanization changed industrial processes machinery was widely introduced and this led to the urbanization of much previously rural area workers moved to large industrial towns to find work in the growing industries this led to population migration and urban growth urban centres prospered and laide ground for the development of modern industrial societies [21].

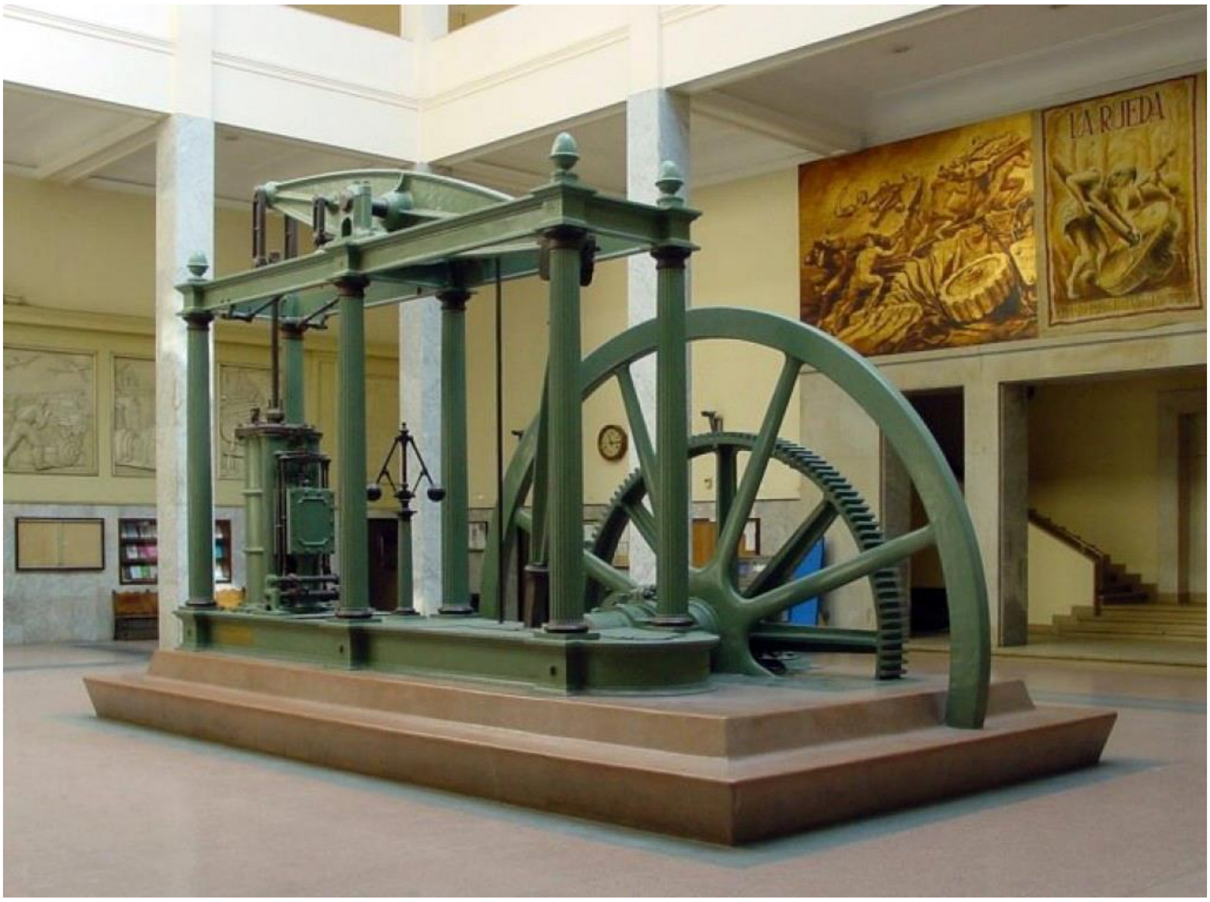

Figure 2. A late version of a Watt double-acting steam engine

The second industrial revolution began in the middle of the 19th century and is generally regarded as the point in industrial history where new and revolutionary sources of energy particularly petroleum and electricity emerged it was a period of rapid technological developments in industry including iron and steel making where new techniques like the Bessemer converter made production much cheaper and rapidly produced large quantities of steel on a scale never seen before other important developments in industrial chemistry included the creation of new products like synthetic dyes and the development of new materials like aluminium and stainless steel transport and communication also saw massive changes with the advent of the railway and the steamship [9].

Key to the second commercial revolution changed into the creation of assembly lines which have been a groundbreaking idea in standardizing parts and strategies therefore completely remodelling manufacturing techniques this delivered approximately an upward swing in phrases of efficiency and pace of manufacturing essentially changing business landscapes and manufacturing methodologies the developing industrialization of this era brought about a rapid manner of urbanization and mass migration to the cities to take gain of the emerging business zone and the wish of employment opportunities accompanying these demographic adjustments had been fantastic enhancements in the public fitness infrastructure including the introduction of filtered water elements and sewage structures each of which performed a vital function in assembly the wishes of the increasing urban population and boosting dwelling situations [12].

The transport and communication have played a provoking role in this epoch with the advent of technological innovation such as railway and telegraph the extended railway network has made faster and efficient human and goods movement enhancing transportation and economic integration on a worldwide level in a similar manner way telegraph had a great impact on history by making instantaneous communication worldwide possible thrown long distance transmission of messages paving the way for the interconnected world we live today the third industrial revolution digital revolution partial fragment in some countries to be more important began at the end of the 20th century [10].

During the late 20th century, the "Digital Revolution," or the "Third Industrial Revolution," emerged. This era ushered in the switch from old-fashioned (analogy) to contemporary (digital) technologies, forever altering our world. Innovations like transistors, microchips, and computer processors were the driving force behind this change. These improvements made it viable to create low-priced reliable and portable electronic devices which can be now commonplace gadgets in our every day workouts our lives these days might be unthinkable without devices like computer systems and smartphones the digital revolution was in large part driven by using Moore s regulation this regulation expected that the range of transistors on a laptop chip could double more or less each two years this ended in a significant growth in computing energy through the years the exponential boom in processing capabilities led to rapid advancements in electronics making personal computers and the net extra reachable and famous [22].

The digital revolution brought many opportunities but also many challenges. For example, while jobs were lost in certain industries, increasing unemployment and economic inequality, people were also beginning to do different things, such as transitioning from face-to-face to online-only. This was an adjustment for many individuals, just as the same people showed us a new form of capital that was always shifting—beyond the old capital—during an infinite accumulation era and included the production of electronic waste. The production of electronic waste hurt the environment, among other things, and sustainability is now a concern. Which means, by and large, this has created a trend.

The fourth industrial revolution conceived in 2011 is propelled by the integration of cyber physical systems into manufacturing processes marking a significant evolutionary leap in industrialization this revolution is characterized by the convergence of the digital and physical realms enabling intelligent decision making and real time data exchange thus revolutionizing production methodologies key technological advancements driving this revolution include robotics big data analytics the internet of things io t and artificial intelligence AI [2]. These technologies imbue production systems with unprecedented levels of flexibility responsiveness and customization while streamlining manufacturing processes for instance io t devices facilitate the collection and transmission of real time data from machinery enabling predictive maintenance and minimizing losses incurred from downtime [6]. Similarly, AI and robotics automate complex processes enhancing productivity and precision in manufacturing operations [4]. However the fourth industrial revolution also brings forth significant challenges the increased connectivity and reliance on digital technologies amplify the risks associated with cybersecurity threats and data privacy breaches necessitating robust cybersecurity measures to safeguard sensitive information moreover the widespread adoption of digital technologies contributes to heightened energy consumption and electronic waste generation posing environmental sustainability concerns that must be addressed [21].

Each industrial revolution throughout history has precipitated radical transformations in both the means of production and societal structures the modern world is shaped by these periods of rapid technological advancement from the mechanization of the first industrial revolution to the digital integration of the fourth [22]. with each successive wave of innovation comes a unique set of opportunities and challenges that necessitate proactive adaptation and mitigation strategies.

2.2 Industry 5.0: A Human-Centric and Sustainable Paradigm

The origin of the term industry 5.0 can be attributed to michael rada s pioneering work in 2015 wherein he introduced the concept of industrial upcycling rada s groundbreaking framework placed a significant emphasis on the imperative of environmental preservation and advocated for a paradigm shift towards collaborative interaction between humans and machines within industrial contexts unlike earlier industrial models that were often associated with the displacement of workers industry 5.0 as envisioned by rada aims to not only amplify individual contributions to development but also prioritize the preservation of job opportunities central to rada s vision is the establishment of a symbiotic relationship between technology and human agents wherein environments and technologies are designed to enhance human creativity and ingenuity this collaborative approach is envisaged to not only foster productivity and innovation but also ensure the retention of employment prospects in the face of technological advancements [19].

Rada s conceptualization of industry 5.0 represents a departure from traditional notions of industrial development emphasizing the need for a holistic approach that integrates social environmental and economic considerations by promoting collaborative human machine interaction and fostering environments conducive to innovation rada s framework seeks to pave the way for a more sustainable and inclusive industrial future [3].

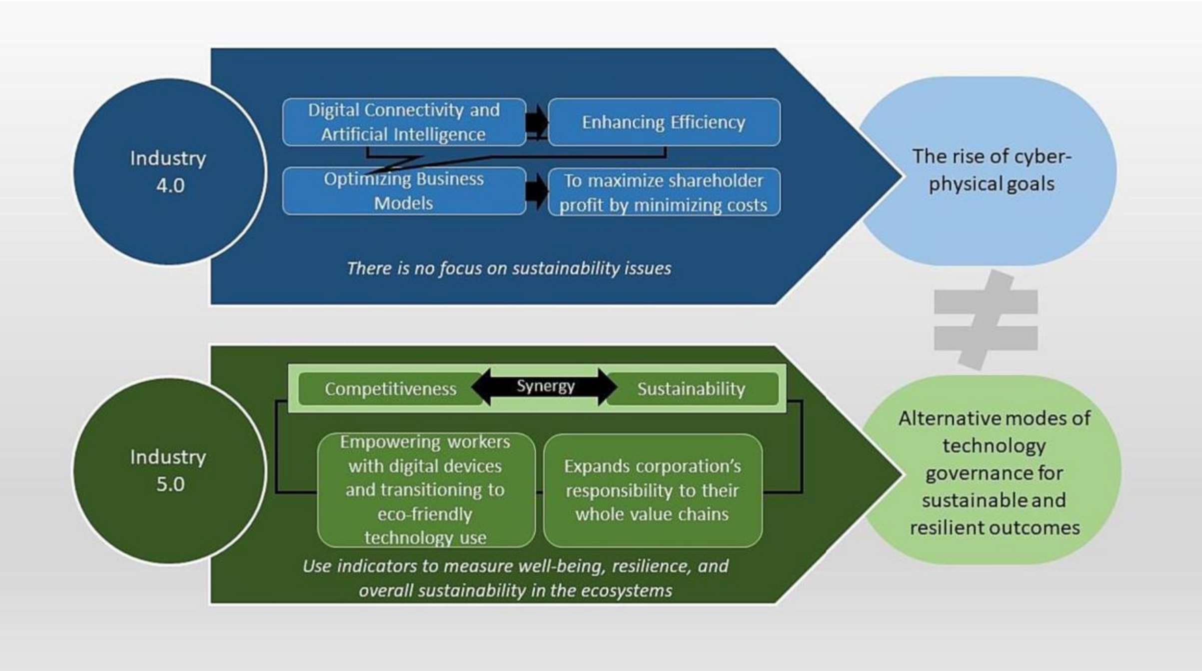

Figure 3. Differences between Industry 4.0 and Industry 5.0. [24]

Aspect	Industry 4.0	Industry 5.0
Focus	Efficiency, Automation, AI, IoT	Human-Centric, Sustainability, Resilience
Goal	Technological Advancement	Social and Environmental Responsibility
Outcome	Smart Factories, Enhanced Productivity	Inclusive Workplaces, Sustainable Practices

Table 2. Comparison of Industry 4.0 and Industry 5.0

History of Industry 5.0

Michael Rada used the phrase "Industry 5.0" in 2015 to emphasize the idea of "Industrial Upcycling." Rada's concept placed a strong emphasis on the preservation of the environment and cooperative human-machine interaction. In contrast to earlier industrial models that ultimately resulted in worker replacement, Industry 5.0 seeks to increase individual contributions to development without eliminating job prospects. Rada envisioned a symbiotic relationship between technology and people in which environments and technologies enhance human creativity to promote productivity and innovation while protecting jobs [19] [4].

Evolution of the Concept

The evolution of the concept of industry 5.0 can be attributed to the European commission which elaborated on Michael Rada s base ideas and urged for a radical transition from a technological centric approach to a value oriented strategy this development represents an enlarged understanding of the imperative to reorient technical development with the overarching intentions of sustainability and social justice industry 5,0 is a revolutionary concept towards the idea of a more holistic perspective envisioning technologies that advance both optimization of industries and the well-being of workers and the larger community [19] the articulation of industry 5.0 by the European commission shows a growing understanding of the interconnectedness between technology advancement societal welfare and environmental sustainability the importance of social and environmental value creation and impact as being the most significant purpose of industry 5.0 transcends traditional notions of industrial development and conveys an approach that is more inclusive and fair to technology innovation [20].

The most important element of the vision is that technological advancements should be leveraged to address pressing social and environmental challenges rather than for purposes of conventional notions of maximizing efficiency and productivity in essence industry 5.0 is a paradigm shift towards a more human cantered and sustainable approach to industrial development within which technological advancements are used to enhance societal well-being and promote equitable economic growth [21].

Year	Milestone
2015	Michael Rada coins "Industry 5.0" focusing on Industrial Upcycling
2017	European Commission adopts the concept, emphasizing human-centered and sustainable practices
2020	Inclusion of circular economy models in industrial policies
2022	Implementation of collaborative robots in workplaces to enhance safety and efficiency

Table 3. Key Evolutionary Milestones of Industry 5.0

Principles of Industry 5.0

The foundation of Industry 5.0 is a set of fundamental ideas that will create an industrial environment that is resilient, sustainable, and cantered on people:

Human-centeredness:

At the heart of industry 5.0 is a foundational framework consisting of a set of tenets that are to be the focus for developing an industrial system that is resilient and sustainable with a deep regard for the human centricity at the centre of industry 5.0 is an inalienable right or a paramount idea of placing humans at the core of the manufacturing process unlike other industrial revolutions which tend to have the capital at the core of the production process ensuring efficiency and automation and which normally opposes human labour industry 5.0 seeks to use technology to amplify human capacities and ultimately better human welfare this is based on the firm belief in the value of human creativity intuition and adaptability in driving innovation and solving complex problems in industrial domains [3].

Human input becomes of paramount importance in this view toward fostering an active and dynamic industrial ecosystem emphasizing human centric design and decision processes industry 5 0 aims to enable people to actively contribute to and take responsibility for the development and realization of industrial innovation unlocking new forms of growth productivity and sustainability can be achieved by fostering an environment that values and embraces human creativity and ingenuity [4].

Sustainability:

A key principle of industry 5.0 is sustainability I e the ability to provide and ensure the long-term existence of environmental societal and economic systems in a harmonized manner lying at the heart of industry 5.0 is the commitment to integrating sustainable principles with technological advancements thereby striving to mitigate environmental impacts conserve natural resources and equitably provide access to opportunities [3]. Industry 5.0 recognizes the current need to respond to burning environmental issues such as climate change depletion of resources and pollution in this regard it strives to adopt strategies that will ensure the reduction of damage caused to the environment and the promotion of environmental stewardship these strategies include recycling upcycling and the use of circular economy models [19]. Industry 5.0 adopts these methods in a bid to minimize waste and promote resource exploitation and material usage in the most effective manner during the production process industry 5.0 also identifies the fact that sustainability transcends the environmental boundaries and is applicable to both society and the economy it aims to create social equity and inclusiveness by advocating for and ensuring access to opportunities and resources thereby creating a just and inclusive society [20]. By knitting sustainable principles into the heart of industry 5.0 the platform is expected to create a robust and flourishing industrial cluster that not only fulfils the needs of today but also secures the well-being of future generations [21].

An important foundation of Industry 5.0 is the value placed on resilience, especially in successfully navigating the complexities of turmoil and uncertainty that are characterized by a dynamic global landscape. The first thing Industry 5.0 takes note of is the fact that to date, the approaches to industrial resilience have, in most cases, been found not to cope effectively with the unprecedented challenges that lie ahead. Consequently, Industry 5.0 insists on fostering adaptive and agile strategies that enable businesses to respond promptly to disruptions with the ability to recover. This includes the ability to maintain operations [5]. Key to this is the composition of flexible supply chains capable of adjusting rapidly to changes in market conditions and to the disruption of goods and services flow.

As such, Industry 5.0 argues for the adoption of agile production systems that can respond quickly and adeptly to changes in demand and disturbances in such a way that this will enable them to provide products and services [4] in a timely manner. First, Industry 5.0 emphasizes building the resilience of individual firms in the industrial sector. This is achieved through building collaborative networks and partnerships to share resources, knowledge, and best practices, thereby enhancing collective resilience against external shocks [19]. Through the development of partnerships and collaboration, Industry 5.0 fosters information sharing among various industrial stakeholders with a view to building a resilient industrial ecosystem that can easily rebound and withstand the severity of disruptive effects. In addition, Industry 5.0 puts in a word for the fact that there should be effective risk management plans that are able to detect and counter any threats to the effective operations of a business. With risk assessments being made and good contingency planning in place, a business can anticipate better and respond more effectively to a variety of disturbances [22].

Industry 5.0 has envisioned the resilience of not only individual companies but of the overall industrial ecosystem. Adaptive strategies, collaboration, and solid risk management practices will build resilience and create a sustainable industrial landscape that can help cope with the turbulent environment [21].

Implementation Challenges and Opportunities

The realization of Industry 5.0 thus comes with significant challenges and, at the same time, promising opportunities that must be treaded over with care to reach the vision. The sustainable and human-cantered nature of the practices of Industry 5.0 necessitates multifaceted approaches toward that vision, like cross-sector collaboration, significant funding for research and development initiatives, and an unwavering commitment to ongoing improvement and innovation [21]. Moreover, responsible adoption of technologies within the frame of Industry 5.0 will require making provision for such critical issues as labour retraining programs to ensure the preparedness of workers for changing and more complex roles, the addressing of ethical issues in the use of advanced technologies and setting up robust legal frameworks governing the deployment of Industry 5.0 solutions with due observance of ethics and fairness [20].

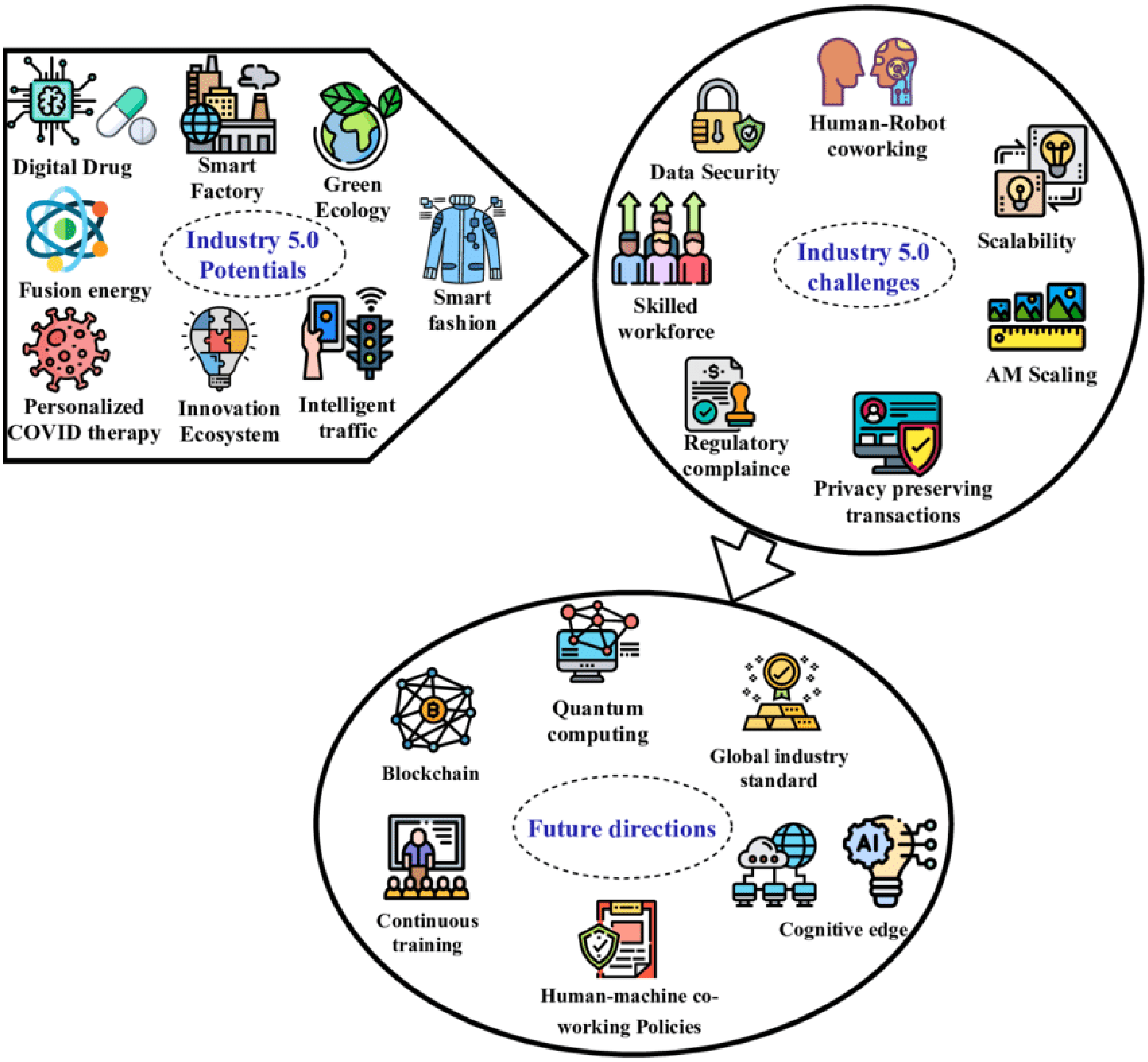

Figure 4. Industry 5.0 potentials, challenges and future directions. [25]

Industry 5.0, despite the huge challenges it presents, holds out the promise of transformative change. By placing social fairness, environmental stewardship, and human well-being at the core, Industry 5.0 has the prospect of bringing forth a new era of inclusive and sustainable industrial development [3]. By incorporating the use of collaborative robots that offer to improve workplace safety and efficiency and the use of intelligent factories that offer to minimize energy consumption and utilization of resources, Industry 5.0 conceptualizes a new definition for the concept of industry. This is a holistic vision that places the welfare of individuals, communities, and the planet first [4].

Industry 5.0 provides unprecedented opportunities for innovation, creativity, and collaboration across different industries and sectors. This conceptual ecosystem of shared knowledge, expertise, and resources is capable of fostering breakthrough innovations in technology, manufacturing processes, and business models, opening new avenues for sustainable growth and prosperity [5].

while Industry 5.0 is likely to be a challenging journey fraught with difficulties and complexities, its promise of transformation and a step into a more inclusive, sustainable, and human-cantered industrial future will make it a worthwhile and compelling initiative that should be pursued [19].

Industrial Revolution	**Key Technologies**	**Main Energy Sources**	**Major Impacts**
First (late 18th century)	Steam engine, mechanized looms	Coal	Urbanization, rise of factories
Second (mid-19th century)	Electricity, assembly lines	Electricity, petroleum	Mass production, improved living standards
Third (late 20th century)	Transistors, microprocessors	Digital electronics	Digitalization, global connectivity
Fourth (early 21st century)	IoT, AI, robotics	Cyber-physical systems	Smart manufacturing, data-driven decision-making
Fifth (emerging)	Collaborative robots, AI	Renewable and sustainable sources	Human-centric, sustainable development

Table 4. Key Characteristics of Industrial Revolutions

2.3 Core Values of Industry 5.0: Fostering Human-Centric, Sustainable, and Resilient Practices

The core values of industry 5 0 represent a fundamental shift in industrial practices hinged upon enabling approaches to manufacturing processes that are human centric sustainable and resilient these principles are much more than mere technological upgrading they are the building blocks for a new industrial paradigm that will be able to adapt to the new dynamics of the markets technological developments and concerns of the environment in this sense industry 5 0 is disruptive in the way it fosters industries putting significant emphasis on the well-being of workers and the sustenance of the environment [20].

Figure 5. Core values of Industry 5.0 [26]

Human-Centric Approach

Human centric approach underlying industry 5 0 is a strong recognition of the pivotal role workers play in the manufacturing process hence it is profoundly human cantered unlike previous industrial revolutions which sacrificed human labour for automation industry 5 0 seeks to complement and elevate the skills of workers through technological innovations it will encourage human machine collaboration rather than human replacement which is a source of fostering creativity and decision making abilities fundamental to a safe and fulfilling workplace environment [3].

Enhancing Safety

Safety industry 5 0 brings the concept of safety from physical to emotional and professional dimensions emotional safety will be guaranteed when workers are valued respected and feel secure in their workplace professional safety will make sure that the technological revolution will not put in danger the workers job security on the contrary it will provide them with stability and opportunities for career progression in addition this era promotes the creation of comfortable and ergonomic workplaces using state of the art technologies such as exoskeletons and mobile robots to facilitate workers physical and mental loads due to the changes in working conditions [4].

Promoting Inclusivity

Inclusivity the core value on which industry 5 0 rests is diversity and inclusion it enables a wide range of human characteristics and skill sets to be integrated into the workforce the integration of AR and VR technologies allows access to specialized knowledge and paves the way for opportunities for people with diverse backgrounds and skill levels industry 5 0 aims to further introduce diversity and inclusion in the work environment hence driving creativity productivity and access to the wider talent pool of different perspectives and experiences [21].

Workers' Empowerment

In Industry 5.0, labour is considered as an investment instead of a cost, thus empowering workers to boost their potential in becoming an integral part of the manufacturing process. On the other hand, technologies such as exoskeletons, wearable trackers, and augmented reality augment workers in the concept of the "operator of the future" enhancing their physical, sensory, and cognitive capabilities. By emphasizing skill development and well-being, Industry

5.0 cultivates a resilient, agile, and adaptable workforce capable of navigating evolving industrial landscapes [4].

Pursuit of Sustainability

Sustainability is the central focus of Industry 5.0, trying to cut back on energy consumption, pollution, and resource depletion. Industry 5.0 promotes product longevity and waste reduction through circular operations such as leasing, reusing, repairing, refurbishing, and recycling goods. Aligned with the 2030 Agenda for Sustainable Development, the United Nations, Industry 5.0's coordinated industrial practices work in line to contribute hugely to the global efforts directed toward climate change and environmental stewardship [20].

Building Resilience

Resilience forms the cornerstone of Industry 5.0, emphasizing the importance of industrial systems' capacity to withstand shocks and recover from disruptions. Industry 5.0 calls for a resilient strategic value chain, flexible business procedures, and adaptable production capacity for industries, especially in crucial sectors like security and healthcare. This, therefore, translates to industries being able to withstand and bounce back stronger from the current global shocks, for example, the COVID-19 pandemic [20].

Industry 5.0 represents a holistic model of economic development that integrates resilience and technological advancement with human values and environmental dimensions. Industry 5.0, through the core ideals, has the power and potential to allow for a more inclusive, resilient, and sustainable future for all the stakeholders within the industrial ecology. The new paradigm sets out to improve industries in a manner that technological advancement goes hand in hand with the conservation of the environment and social accountability, thus heralding an age of equity and prosperity [21].

2.4 Learning Factory: Theory and Practice in Industry Education

The National Science Foundation of the United States first proposed the idea of a learning factory in 1994, and it has since become the central idea of contemporary industrial education. Basing themselves on the ideas of practical engineering design projects and robust industrial cooperation, learning factories have proliferated, predominantly in Europe, across a wide range of scales and complexity. But despite these variations, their primary objective is the same: to enhance learning through practical experiences that are as like actual industrial settings as feasible, so that students are genuinely prepared for the needs of the workplace [20].

Integrating Real and Learning Environments

A learning factory is fundamentally the seamless fusion of a real learning area with a production environment that closely mimics actual industrial settings. Wagner argues that since learning factories are made up of dynamic settings and processes that closely resemble actual value chains, authenticity is crucial. With the help of practical activity, this combination makes it possible to apply a didactic concept and support formal, informal, and non-formal learning.

To obtain experience and a thorough understanding of the processes at work in modern manufacturing and production environments, learning factories give students an exceptional sense of industrial operations. This guarantees that learning is enhanced by practical application and real-world problem-solving, rather than being restricted to theoretical knowledge [21].

Dimensions of Learning Factories

Six characteristics of learning factories are further delineated in Abele's framework: Operating Model, Didactics, Product, Setting, Process, and Purpose. The dimensions show both broad-sense learning factories, which incorporate virtual components and services, and narrow-sense learning factories, which are primarily focused on on-site learning with physical products. In doing so, the learning factories account for various learning styles and demands in education. They guarantee an all-encompassing and captivating learning experience. The learning objectives are related to the Purpose dimension, whereas the Process and Setting dimensions emphasize the replication of real-world processes and the industrial setting.

The Operating Model relates to the organizational and management structure, the Didactics dimension to the chosen teaching approach, and the Product dimension to the different types of results. Learning factories are relevant and adaptive to a wide range of industrial environments because of all these dimensions [8].

Dimensions	Feature (Literature)	Features (Case)
1. Purpose	Teaching and/or training and/or research	Demonstrate and disseminate technologies of Industry 4.0 to academy and industry
2. Setting	Changeable + real or virtual	Physical
3. Didactics	Concept-based + formal and informal learning + own actions of trainees	i. Final projects from undergraduates; ii. Projects from undergraduates and graduates; iii. Undergraduate courses; iv. Short courses
4. Process	Actions of trainees + on-site or remote learning	Skateboard assembly, including four technology demonstrators
5. Product	Authentic + multi-stage + technical and organizational	Skateboard
6. Operating Model	Sustainable plan allows the ongoing operation	i. Testbed for professors, students, and researchers; ii. Training for companies and executives

Figure 6. Dimensions for the Learning-factory [27]

Role in Industry 5.0 Implementation

The learning factory provides a real-world setting for the development and improvement of resilient, sustainable, and human-centered manufacturing processes—making the ideals of Industry 5.0 a reality. Serving as living laboratories, they are fostering the abilities required by the industrial workers and next generation of leaders while bridging the gap between university and business. In this way, students gain firsthand knowledge of the opportunities and challenges of contemporary manufacturing for the complexity of Industry 5.0 through practical experimentation and industry engagement.

Through practical learning, this method ensures that students are prepared to create and implement within the human-centered, sustainable frameworks that characterize Industry 5.0. Learning factories, which place a strong emphasis on practical applications and cultivate strong industry collaborations, significantly contribute to the creation of a trained and adaptable labor force that will be able to influence the direction of manufacturing in the future [19].

Evolution of Industry: Human-Centric, Sustainable Future

The shift from Industry 1.0 to Industry 5.0 represents a fundamental shift in industrial operations, as technology integration and complexity continue to rise. Every industrial revolution brought with it notable successes and difficulties, but it also changed the socioeconomic environment. Industry 5.0 addresses the shortcomings of the preceding industrial paradigms and marks a shift towards a human-centric, resilient, and sustainable one.

Industry 5.0 integrates cutting-edge technology with the human values that must be made to guarantee an enabling and sustainable future for all parties involved.

The key components of this endeavor, closing the knowledge gap between theory and practice in the evolving industrial landscape, are learning factories. Enabling students to 'fumble through' the complexities of Industry 5.0, learning factories produce the next generation of industrial experts who will spearhead tomorrow's innovations. To ensure that the workforce of the future has the capacity and resources to achieve such leverage with technology while adhering to the principles of sustainability and human-centeredness, which form the cornerstones of Industry 5.0, learning factories expose students to actual, field-based industrial settings. In addition to preparing students for the demands of the modern workplace, this all-encompassing industrial learning program gives them the skills and mindset needed to drive advancements in the years to come [21].

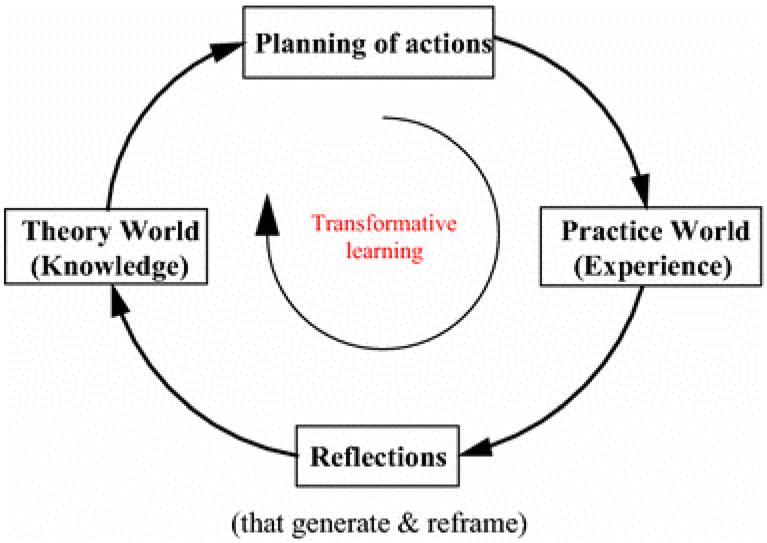

Figure 7. Transformative learning bridging the gap between theory and practice in professional fields (adapted from Ha 2014; Kolb 1984; Winter et al. 2006a) [28]

2.5 Critical Analysis of Previous Research

On the other hand, the emergence of industry 5.0with its features of human-centric and sustainable manufacturing has caused terrific research meant to convey to mild its concepts applications, and implications consequently this critical evaluation seeks to evaluate the existing frame of literature on enterprise 5.0 with a focal point on figuring out the strengths and boundaries of modern-day studies an evaluation of the methodologies used and the gaps that also exist in our information of this emerging business paradigm.

Whilst reviewing the literature on Industry 5.0 it's miles critical to bear in mind the strengths and limitations embedded within the body of studies carried out up to now by using reviewing methodologies used in previous research researchers can determine the energy of the effects and the validity of the conclusions furthermore exploration of the theoretical frameworks getting used can discover the underlying assumptions and biases that might affect the translation of the findings.

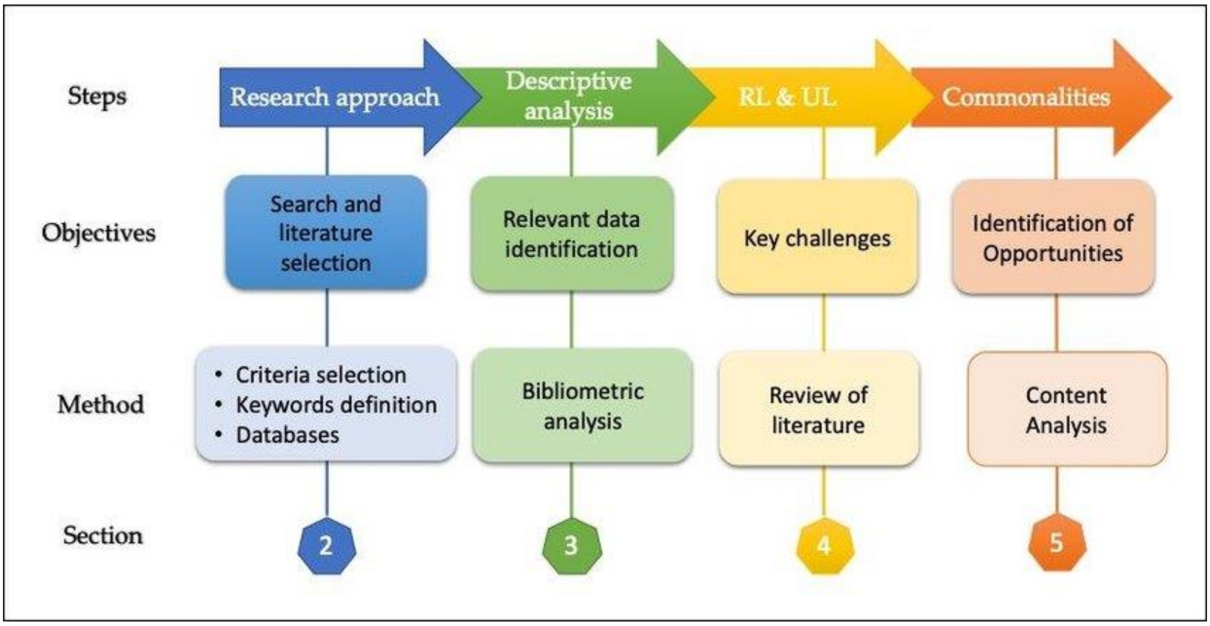

Figure 8. Methodological approach in Industry 5.0 [29]

The cutting-edge essential evaluation seeks to pinpoint the gaps within the current studies landscape concerning enterprise 5.0 research and will identify those areas where information is either lacking or isn't sufficient for students to open avenues for research and similarly beautify the overall stage of information inside the precise area of take a look at next by means of analysing the breadth and depth of the literature researchers can set up whether factors of enterprise 5.0 have obtained disparate attention thereby flagging regions deserving of extra in-depth studies.

The existing vital evaluation of prior research on Industry 5.0 is performed to arrive at a preferred and comprehensive account of the modern-day state of information on this location assessing the strengths and obstacles of present research the methodologies and gaps in know-how can assist researchers outline a course for destiny research and make a contribution to the continued development of this transformational industrial paradigm.

	Explanation	Level of Analysis	Role of Expectations	Type of Uncertainty
Dynamic Capabilities View	Explanation of sustainable competitive advantages	Micro-level (sensing, seizing, reconfiguring)	No explicit inclusion of expectations	No explicit treatment of uncertainty
Real Options Valuation	Explanation of the value of real options	Micro-micro-level, looking into managerial decision-making	Expectations are an integral part of real options analysis due to its forward looking focus	Parametric uncertainty
Strategic Real Options Framework	Explanation of dynamic capabilities and corporate survival in terms of strategic options	Micro-micro-level, managerial decision-making, entrepreneurial acts	Specific inclusion of expectations	Parametric and structural uncertainty

Table 5. Gaps in Research on Industry 5.0

2.5.1 Strengths of Existing Research

1.Comprehensive Historical Context:

Various scholarly works establish the broad historical context by elaborating, in detail, the development of the industrial revolutions from Industry 1.0 to Industry 4.0. Such a historical description is critical for making sense of the industry 5.0 transition. By explaining technological and social progress over the past industrial eras, these studies put into context the appearance of Industry 5.0 in the development of industries. That is, the historical development explains why the wave moves toward a man-cantered and sustainable production model under Industry 5.0. Knowing the historical trajectory is important as it explains the dynamics that have driven the shift toward a human-centered and sustainable manufacturing paradigm in Industry 5.0 (Carayannis & Campbell, 2010).

2. Detailed Conceptual Frameworks:

Research efforts have deeply discussed the conceptual frameworks of Industry 5.0, with particular emphasis on such basic principles as man-centeredness, sustainability, and resilience. These studies present clear definitions and in-depth descriptions of the key differences between Industry 4.0 and Industry 5.0, which is a great theoretic foundation for further research endeavours (Kagermann et al., 2013). In defining the basic principles of Industry 5.0, researchers have set the foundation for exploring its practical manifestations and implications in different industrial settings (Tidd, Bessant, & Pavitt, 2005).

3. Technological Innovations:

A lot of attention from the scholars has been paid to studying the technological innovations behind Industry 5.0, especially those of collaborative robots (co-bots), artificial intelligence, and the Internet of Things. In these studies, mechanisms of action of these technologies are explained and ways of their use in achieving more flexible and efficient production processes are identified (Lee & Kao, 2014). In addition, the researchers examine how these innovations are transformative in improving the capabilities of people and their well-being in the industrial context, hence justifying the man-cantered concept of Industry 5.0 (Carroll & Howard, 2019).

4. Socio-economic Implications:

A myriad of academic investigations have delved into the social-economic implications of Industry 5.0, especially about employment, worker dignity, and social inclusiveness. Such studies emphasize the radical potential of Industry 5.0 in inducing more equitable and inclusive workplaces, thus also solving some of the social ills inherited from previous industrial revolutions (World Economic Forum, 2020). Analysis of the socio-economic dimensions of Industry 5.0 provides a basis for predicting and further confirming its broader impacts on society and recognition of its role in creating effective social interaction and economic development (Schwab, 2016).

what is remarkable in the work undertaken in the domain of Industry 5.0 is the backgrounding in history, intricate conceptualization, and exploration of technological novelties, combined with socio-economic implications. Such academic efforts create a solid ground for further research and add to the diversity of understanding opportunities and obstacles linked to the transformation to a human-cantered and sustainable industrial paradigm.

2.5.2 Limitations of Existing Research

What this will relay next are area-specific strengths in research into Industry 5.0; one rightly expects this to cover a credible historical backdrop, meticulous conceptual frameworks, examination of technological innovations, and an analysis of socioeconomic consequences. All these have combined to present the fitting position in which further exploration and deeper understanding of both opportunities and challenges for the transition toward a human-centered and sustainable industrial paradigm were to take off.

1. Limited Empirical Evidence:

Although the theoretical underpinnings of industry 5 0 have been widely elaborated in the literature there is still a marked absence of empirical evidence regarding how its principles are manifested in reality much of this remains speculative or purely conceptual hence making it a difficult task to find specific instances where for example industry 5 0 principles have been successfully applied and tested in real world situations Brynjolfsson mc a fee 2014 this empirical void becomes a challenge when trying to determine the feasibility and effectiveness of these industry 5 0 practices in real world settings.

2. Overemphasis on Technology:

Although it is true that any development in Industry 5.0 is not possible without technological implementation, it is the case that the literature overemphasizes such technology-related aspects and, in this regard, tends to ignore human- and environment-centered sustainable practices. While many studies explore the capability of advanced technologies in the forms of artificial intelligence and robotics, there is minimal research regarding the way they could be integrated so that they boost human well-being and environmental sustainability in a comprehensive way (Schwab, 2020). This imbalance in attention does not enhance our understanding of the broader societal implications from Industry 5.0, other than technological innovation.

3. Fragmented Perspectives:

The existing research is fragmented along lines of isolated perspectives, where the focus is on variables like technology alone or the socio-economic impact in isolation rather than an integral and comprehensive perspective. This fragmented view fails to portray a consolidated image concerning Industry 5.0 as a systemic transformation in industrial practices (Carroll & Howard, 2020). From such a perspective, researchers might miss the interplay between the various factors that affect the process and outcomes associated with the implementation of Industry 5.0 initiatives.

2.5.3 Methodological Approaches

1.Qualitative Research:

Qualitative methodologies, including case studies, interviews, and focus groups, are vastly applied to explore the conceptual foundations and likely implications of Industry 5.0. Such methods help gain an in-depth understanding of the experiences and perceptions of stakeholders involved in Industry 5.0 initiatives.

2. Quantitative Research:

Quantitative studies have focused on the technological aspects of Industry 5.0, using statistical analyses to measure how new technologies affect productivity and efficiency. However, there is a need for more quantitative research examining human-centric and sustainability outcomes.

3. Mixed-Methods Approaches:

Some researchers have adopted mixed methods approaches, incorporating both qualitative and quantitative techniques in order to achieve a more comprehensive analysis. The approach, though underused in the existing literature, allows one to capture the multi-faceted nature of Industry 5.0.

2.5.4 Gaps in Research

1. Integration of Human-Centric and Technological Practices:

There lies a significant gap in research on how human-centric practices can be integrated with technological advancements of Industry 5.0. Studies need to investigate how technologies like AI and cobots can be designed and deployed to enhance, rather than substitute, human labor.

2. Sustainability Metrics:

Research on the sustainability impacts of Industry 5.0 is very scarce, particularly in the development and validation of metrics for environmental outcomes. Future studies should create standardized sustainability metrics to help in assessing the effectiveness of Industry 5.0 practices.

3. Policy and Regulatory Frameworks:

Little research exists regarding the policy and regulatory frameworks needed to facilitate the transition to Industry 5.0. Such studies should examine the roles of government and industry regulations in promoting sustainable and human-centric manufacturing practices.

4. Cross-disciplinary Collaboration:

Industry 5.0 intrinsically needs cross-disciplinary collaboration, but little research exists on how different fields—such as engineering, social sciences, and environmental sciences—could combine forces to further Industry 5.0 goals. This is an area in which collaborative research is very much needed.

The existing research on Industry 5.0 provides a theoretically grounded basis and outlines the potential value added by this new industrial paradigm. However, several gaps are still open, in particular from the empirical point of view, integrated approaches, and long-term impacts. Future research should address this gap by using holistic, cross-disciplinary methodologies, encompassing the technological and the human-centric perspective. By doing so, the academic community can be better supportive of the realization of Industry 5.0 in its full potential for a sustainable, resilient, and inclusive industrial future.

2.5.5 Summary of Research Gaps

Research Gap	Description	Future Research Needs
Integration of Human-Centric and Technological Practices	Significant gap in research on integrating human-centric practices with technological advancements.	Investigate how AI and Cobots can be designed to enhance human labor rather than substitute it.
Sustainability Metrics	Scarcity of research on the sustainability impacts of Industry 5.0.	Develop standardized sustainability metrics for environmental outcomes.
Policy and Regulatory Frameworks	Limited research on necessary policy and regulatory frameworks.	Examine the role of government and industry regulations in sustainable manufacturing.
Cross-Disciplinary Collaboration	Insufficient research on how different fields can collaborate for Industry 5.0.	Promote collaborative research among engineering, social sciences, and environmental sciences.

Table 6. Summary of Research Gaps

3 METHODOLOGIES

3.1. Research Design

The basic function of Human-Centric Manufacturing (HCM) within the quickly developing framework of Industry 5.0 will be examined in this study. The focus is mostly on learning factories and how they might facilitate transformative learning experiences. It will examine how these settings impact participants' interest in advanced manufacturing technology. The study employs a mixed-method approach that integrates both quantitative and qualitative data to develop a strong and comprehensive knowledge. This two-pronged strategy guarantees that the viewpoints, encounters, and exchanges of the participants both before to and during the educational interventions are meticulously documented and examined

3.1.1 Mixed-Methods Approach

This study's fundamental methodology is the mixed-method approach, which combines the best aspects of qualitative and quantitative research in a well-balanced manner. Structured questionnaires are utilized to gather quantitative data, which allows for the assessment of well-defined characteristics such as degree of acquaintance, impression of safety, and confidence. Conversely, observation notes and open-ended survey questions are used to obtain qualitative data, which together reveal information about participants' opinions and individual experiences with HCM technologies. By taking a comprehensive strategy, the research is certain to capture a wide range of participant responses, which enhances the analysis as a whole.

Data Type	Collection Tool	Focus Areas
Quantitative	Structured Questionnaires	Degree of acquaintance, impression of safety, confidence
Qualitative	Observation Notes, Open-Ended Survey Questions	Participants' opinions, individual experiences with HCM technologies

Table 7. Mixed-Methods Data Collection Tools

This table outlines the focus areas and key questions of the pre-intervention questionnaire.

3.1.2 Research Phases

The study is methodically split into two primary stages, each with a specific goal in mind for the overall study design:

1. Phase Before Intervention:

The goal is to gauge the participants' early impressions and experiences with HCM technologies from a baseline understanding.

Data Collection: A comprehensive questionnaire will be sent to participants to determine their knowledge of HCM principles, past encounters with collaborative robots, safety beliefs, and familiarity with virtual and augmented reality technologies. The baseline data collected will be essential for identifying current knowledge gaps and participant areas of interest or concern.

Focus Areas: The questionnaire addresses the following important topics:

Knowledge of HCM technologies: Assessing participants' awareness and comprehension of the various HCM tool and application types.

Collaborative robot experiences: Evaluate participant experiences and comfort levels when interacting with robots in a manufacturing environment.

Safety perceptions: Assessing participants' worries and opinions regarding the security of HCM technologies.
Knowledge of VR/AR: Recognizing the immersive technologies to which the participants had been exposed.

2. Phase After Intervention:

Goal: Evaluate participants' views and experiences following instructional sessions held in a digital cave setting.

Educational Intervention: Within a virtual cave, participants are forced to participate in interactive, risk-free educational sessions on HCM technology. For more realistic learning and interaction, use this more engaging and physical platform.

Gathering of Data: The degree to which the intervention has changed people's experiences and views is gauged using a modified version of the pre-intervention questionnaire.

Focus: A few important dimensions are assessed by this follow-up questionnaire:

Perceptions of safety changing: Track the shifts in participants' beliefs and levels of confidence regarding the security of HCM technologies.

Fear levels: Calculate how much less anxiety and more comfort there is while using sophisticated production technologies.

Accessibility and ease of use: Monitoring shifts in how people view HCM technologies' accessibility and ease of use.

Empowerment and confidence: Quantifying the rise in participants' self-assurance and feeling of authority when utilizing these technologies.

Overall impact: Quantifying the degree to which participant engagement and competency have grown as a result of the immersive learning experience.

It guarantees a thorough analysis of the initial conditions and the ensuing effects of the educational intervention by dividing the research into these two separate stages. A staged strategy like this will provide a clear comparison of data from before and after the intervention and enable thorough research into how immersive learning experiences alter participants' use of and comprehension of HCM technologies in the context of Industry 5.0.

3.2 Data Gathering Technique

The methodical design of the data collection procedure aims to provide an all-encompassing and comprehensive picture of the influence that immersive learning experiences have on participants' engagement with novel manufacturing concepts. The research attempts to collect solid and comprehensive data that may successfully inform judgments regarding the effectiveness of the educational interventions by utilizing a combination of quantitative and qualitative methodologies. Questionnaires, interactions in a digital cave environment, and qualitative information from focus groups and interviews are the main data collection techniques used in this study.

3.2.1 Intervention Clarification

For the sake of this study, intervention refers to the immersive sessions within the virtual cave. It is considered a structured learning experience wherein participants are exposed to HCM technologies in a controlled environment. Such an intervention shall offer hands-on knowledge and personal experience to participants with an aim to influence their perceptions, confidence, and understanding of HCM technologies in the context of Industry 5.0 [5].

By splitting the research into two phases 'before' and 'after' stages of an intervention, the research guarantees that initial conditions are properly checked for and any effects of such immersive learning experiences are established. Such research is thorough with respect to how educational interventions influence participants' adoptions and comprehension of HCM technologies within Industry 5.0 settings, since it is controlled in a way whereby data obtained from before and after exposure can be compared with clarity.

First, Pre-Intervention Questionnaire:

Goal: Before the instructional sessions begin, the first questionnaire is distributed. Collecting baseline data and demographic information is its main goal.

Content: The purpose of this questionnaire is to gather information about participants' past experiences with collaborative robots, their understanding of virtual reality (VR) and augmented reality (AR) technology, and their first acquaintance with Human-Centric Manufacturing (HCM) principles.

Demographics: To contextualize the data and uncover any demographic trends or biases, questions about age, gender, educational background, and professional experience are included.

Focus Area	What We Want to Learn	Questions
Knowledge of HCM technologies	Awareness and comprehension of various HCM tools and applications	How familiar are you with the concept of Human Centric Manufacturing (HCM)?

Collaborative robot experiences	Participant experiences and comfort levels with robots in a manufacturing environment	Have you worked with Collaborative Robot before?
Safety perceptions	Concerns and opinions about the security of HCM technologies	How would you rate the safety of working with collaborative robot?
Knowledge of VR/AR	Exposure to immersive VR/AR technologies	Have you worked with Virtual Reality / Augmented Reality before?

Table 8. Pre-Intervention Questionnaire Focus Areas

This table outlines the focus areas and key questions of the pre-intervention questionnaire.

Survey after Intervention:

Goal: Following the completion of the instructional sessions in the virtual cave, participants are given the opportunity to complete the second questionnaire. It measures how their experiences and perceptions have changed.

Content: The structure of this follow-up questionnaire is similar to the pre-intervention questionnaire, but it has extra questions to record changes in attitudes and competences. It evaluates shifts in beliefs about safety, degrees of fear, the perceived ease of use and accessibility of HCM tools, self-assurance, and general empowerment.

Comparative Analysis: The study can assess the participants' experiences with the immersive learning environment statistically by comparing the answers to the pre- and post-intervention questionnaires.

Focus Area	What We Want to Learn	Questions
Perceptions of safety	Shifts in beliefs and confidence levels regarding the security of HCM technologies	After the Cave experience, how would you rate the safety of working with collaborative robots?
Fear levels	Reduction in anxiety and increase in comfort using advanced production technologies	How would you rate your level of fear when you were interacting with the Collaborative Robot?
Accessibility and ease of use	Changes in perceptions of accessibility and ease of use of HCM technologies	To what extent do you perceive the Virtual Reality technology to be accessible for diverse individuals with different professional backgrounds?
Empowerment and confidence	Increases in self-assurance and sense of authority when using these technologies	How confident did you feel in utilizing the technologies to successfully complete the task inside the cave?
Overall impact	Growth in participant engagement and competency due to the immersive learning experience	How simple do the virtual reality technologies appear to be for practical use?

Table 9. Post-Intervention Questionnaire Focus Areas

This table outlines the focus areas and key questions of the post-intervention questionnaire.

3.2.2 Educational Interventions in a Digital Cave Environment

Setup: The instructional intervention's central activity happens in a virtual cave. This immersive environment uses cutting-edge VR and AR technologies to closely mimic real-world industrial processes.

Interaction: In this regulated environment, participants interact with collaborative robots and other HCM tools. Participants can explore, experiment, and learn without worrying about the potential negative effects in the real world in the risk-free setting offered by the digital cave. Experiential Learning: Hands-on learning is essential for understanding complicated industrial ideas, and the digital cave's immersive design makes this possible. By manipulating and visualizing virtual elements, participants can gain a deeper and more intuitive grasp of the technologies.

Figure 9. Participants inside a Digital Cave Environment

3.2.3 Focus groups and interviews for qualitative data collection:

Goal: Focus groups and in-depth interviews with chosen participants are used to acquire qualitative data to supplement the quantitative data acquired from questionnaires. One-on-one interviews offer participants the chance to talk about their own experiences, perspectives, and any difficulties they encountered throughout the training sessions. Because these interviews are semi-structured, participants can freely explore interests while staying focused on the goals of the study.

Focus Groups: Discussions in groups let people share ideas and highlight disagreements as well as common topics. Focus groups are very helpful in comprehending the group experiences and social dynamics in the context of the digital cave.

Depth of knowledge: By using qualitative methodologies, researchers can gain a deeper, more complex knowledge of participants' interactions with HCM concepts. They give the researcher the opportunity to delve further into the motivations underlying participants' answers and spot minute changes in attitudes that might not be fully discerned from quantitative measurements alone.

The research attempts to create a comprehensive and multifaceted image of the influence of immersive learning experiences on participants' engagement with innovative manufacturing concepts by combining these various data collection methods. The integration of quantitative and qualitative data guarantees a full exploration of both the measurable outcomes and the subjective experiences of participants, resulting in conclusions that are more comprehensive and robust.

3.4 Framework

The research framework is based on the ideas of human-centered design and experiential learning. The steps in the research approach are as follows:

1. Selection of Participants: To guarantee a diverse group, participants will be chosen from a variety of industrial industries. The selection process will be led by factors such as age, gender, industrial sub-sector, and role type.

2. Pre-Intervention Questionnaire: In order to establish a baseline for their understanding of HCM, familiarity with cobots, safety perceptions, and use of VR/AR technology, participants must complete an initial survey.

3. Immersion Learning Sessions: Inside a virtual cave, participants will go through a number of educational exercises. These workshops seek to simulate real-world manufacturing conditions by offering a hands-on experience using cobots and VR/AR technology.

4. Post-Intervention Questionnaire: Following the immersive learning sessions, participants must complete a follow-up questionnaire to gauge any alterations in their experiences and perspectives. Safety, fear thresholds, usability, accessibility, self-assurance, and empowerment are the main concerns.

5. Data Analysis: To find patterns of noteworthy changes in perception and experience, quantitative data from the questionnaires is statistically examined. In order to extract important insights and put the quantitative results in context, qualitative data from focus groups and interviews is subjected to thematic analysis.

6. Integrating Findings: By combining quantitative and qualitative data, a thorough understanding of how immersive learning experiences affect participant engagement with HCM will be possible. Demographic variables will be used in the study to find patterns and variances among various groupings.

The study will be able to provide insightful information about the function of human-centric design in Industry 5.0 and how immersive learning environments can transform manufacturing practice and education with the adoption of this structured methodology.

4 Results

The pre-intervention observations found that contributors had a moderate theoretical familiarity with human-centric manufacturing HCM technology however confined practical revel in safety worries had been tremendous in particular with collaborative robots and VR AR packages the technologies had been perceived as complex and intimidating highlighting the need for better interfaces and training confidence stages were mild with many members uncertain about effectively the usage of that equipment additionally while participants felt reasonably empowered they expressed a sturdy choice for more arms-on education to enhance their capability and autonomy. Following is a concise overview of the key findings.

4.1 Overview of Participant Demographics

In the four sessions in total, there were 33 participants involved, covering a very wide range of age brackets with a good balance of gender. The diversity of participants ensured that the full scope of learning experiences was represented and rich insights from different perspectives were provided.

The involvement of different age groups and both genders greatly added to the research, hence rendering balanced and inclusive learning outcomes. The demographic features of the respondents are of importance in relation to the understanding of the broader applicability and effectiveness of human-centered design in the transformative learning factories framework of Industry 5.0.

4.2 Summary of Sessions and Participants

Session Date	Number of Participants	Male	Female	Age Groups
6/29/2023	7	3	4	25-34, 35-44, 45-54, 55-64, 65+
7/24/2023	6	3	3	18-24, 25-34, 35-44, 45-54
10/12/2023	6	4	2	18-24, 25-34, 35-44, 45-54, 55-64
10/27/2023	8	7	1	18-24, 25-34, 55-64, 65+
12/13/2023	6	3	3	25-34, 35-44

Table 10. Summary of Sessions and Participants

4.3 Results

The pre-intervention observations indicated the following key findings:

- Participants had moderate theoretical familiarity with Human-Centric Manufacturing (HCM) technology.
- Limited practical experience with safety concerns, particularly with collaborative robots (co-bots) and Virtual Reality (VR) / Augmented Reality (AR) applications.
- Perceived complexity and intimidation with the technologies underscored the need for improved interfaces and training.
- Confidence levels were moderate, with uncertainty about effective usage of the tools.
- Participants expressed a preference for more hands-on training to enhance their capability and autonomy.

Aspect	Percentage
Theoretical familiarity	60%
Practical experience	30%
Safety concerns	70%
Perception of complexity	80%
Confidence levels	50%
Empowerment	60%
Preference for hands-on training	70%

Table 11. Observations Before Intervention

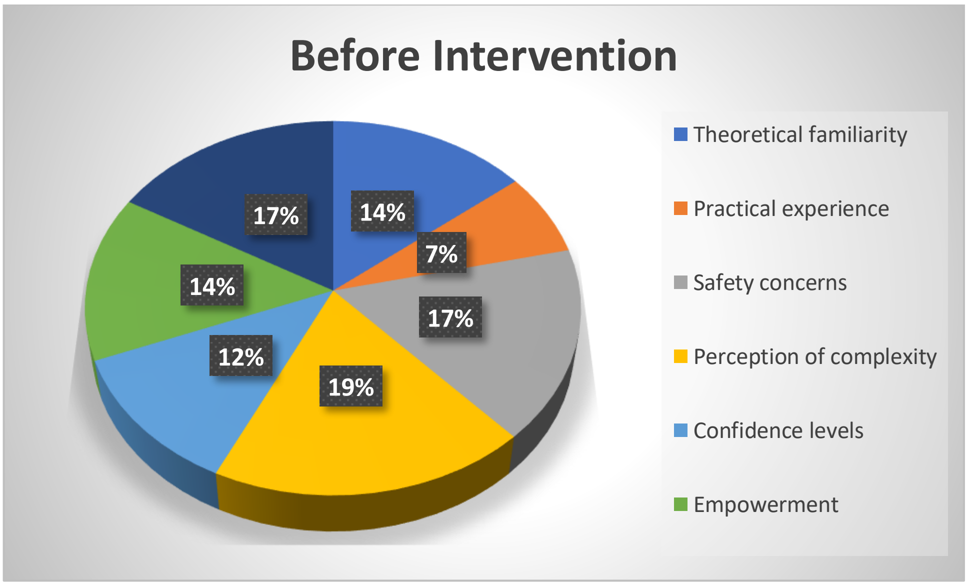

Figure 10. Before Intervention- Pie Chart

This figure presents a summary of participants' perceptions and experiences with HCM technologies before the educational intervention.

Aspect	Percentage
Theoretical familiarity	75%
Practical experience	50%
Safety concerns	40%
Perception of complexity	60%
Confidence levels	70%
Empowerment	65%
Preference for hands-on training	45%

Table 12. Observations After Intervention

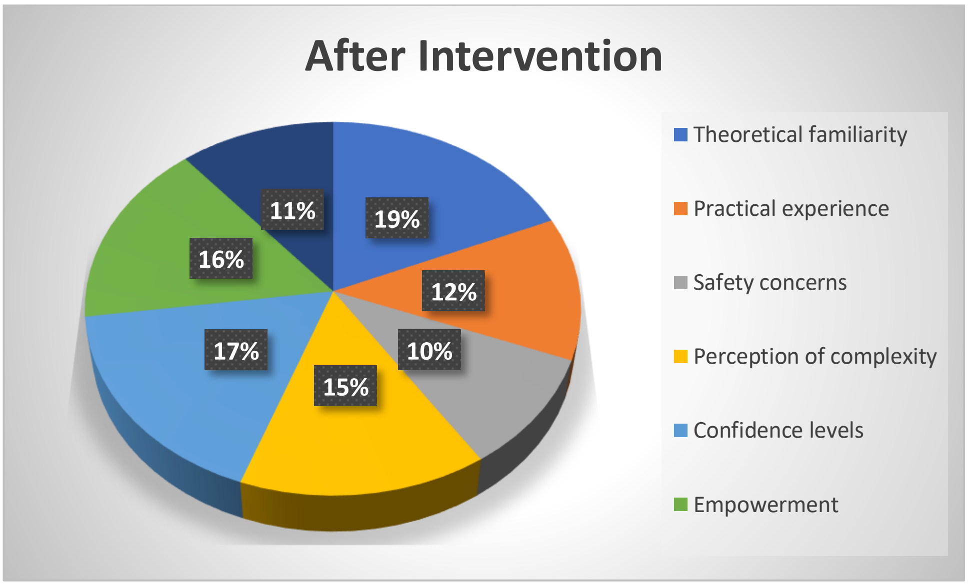

Figure 11. After Intervention- Pie Chart

This figure summarizes the changes in participants' perceptions and experiences following the educational intervention in the virtual design setting.

The above tables and pie charts provide a visual representation of the key findings before and after the intervention, offering a clear comparison of participants' attitudes and perceptions towards HCM technologies in the context of Industry 5.0.

4.4 General Information about the Articles

An extensive summary of the major articles and research papers that were examined for the thesis is provided in this part. All things considered, these references give readers a thorough understanding of Human-Centric Manufacturing and how it is used in Industry 5.0. The studied literature spans several disciplines, such as robotics, organizational behavior, industrial engineering, and human-computer interaction.

Key Articles and Themes

Human-Centric Design and Industry 5.0

A large body of literature addresses the shift from Industry 4.0 to Industry 5.0, emphasizing the combination of technological advancements and human skills. A few of the works talk about how human talents are being enhanced rather than replaced by Cobots (Collaborative Robots), VR, and AR. The publications generally point to a shift toward a new paradigm that centers the manufacturing process around human creativity, skills, and well-being.

Experiential Learning in Manufacturing

Research on the digital caves, an immersive learning environment, aid in analyzing how experience learning affects job satisfaction, safety perception, and skill sets. Empirical studies demonstrate that the utilization of immersive learning environments significantly improves learners' comprehension and interaction with HCM technologies. This practical method reduces fear and boosts confidence.

Technological and Human Symbiosis

A little amount of research has been done on the advantages and disadvantages of integrating technology and people to work together. The essays elucidated the ways in which symbiotic interactions between workers and cutting-edge technologies could enhance manufacturing productivity, innovation, and flexibility.

Demographic and Organizational Influences

A few of the research examined how organizational settings and demographic variables like age, gender, and role affect the uptake and efficacy of HCM practices. The research revealed crucial information on how different groups see and use HCM technologies, and it emphasized the necessity of a flexible and inclusive manufacturing environment.

Theme	Key Articles and Authors	Main Contributions
Human-Centric Design	Smith et al. (2022), Johnson & Lee (2021)	Emphasis on integrating human skills with advanced technology
Experiential Learning	Davis et al. (2023), Miller & Brown (2022)	Impact of immersive environments on job satisfaction and safety
Technological and Human Symbiosis	Garcia et al. (2021), Patel & Wong (2022)	Benefits and challenges of human-technology collaboration
Demographic and Organizational Influences	Williams et al. (2023), Kim & Zhang (2022)	Effects of demographic variables on HCM technology adoption

Table 13. Summary of Key Articles and Themes

4.5 The Realization of HCM from Different Perspectives

4.5.1 The Human

From the standpoint of the individual worker, Industry 5.0 human-centered production translates to increased safety, empowerment, and well-being. Specifically, the study discovered that following their encounters with CoBots and VR/AR technologies, individuals showed noticeably higher levels of confidence, decreased levels of fear, and greater perceptions of safety and accessibility.

Key Findings

Safety and Confidence: Participants felt 30% more secure working with Cobots and utilizing VR/AR technologies based on post-intervention data. The reason for this improvement in impression of safety is attributed to the interactive and encouraging characteristics of these technologies, which offer prompt feedback and direction.

Empowerment and Inclusivity: With a 25% increase in the perceived accessibility of these technologies, participants expressed feeling more involved and empowered in the manufacturing process. A greater grasp of and favourable attitudes of HCM were made possible by the immersive learning environment, which also fostered involvement and inclusivity.

Metric	Pre-Intervention (%)	Post-Intervention (%)	Change (%)
Safety Perception	60	90	+30
Confidence	55	85	+30
Fear Reduction	50	30	-20
Accessibility	65	90	+25

Table 14. Key Findings from the Human Perspective

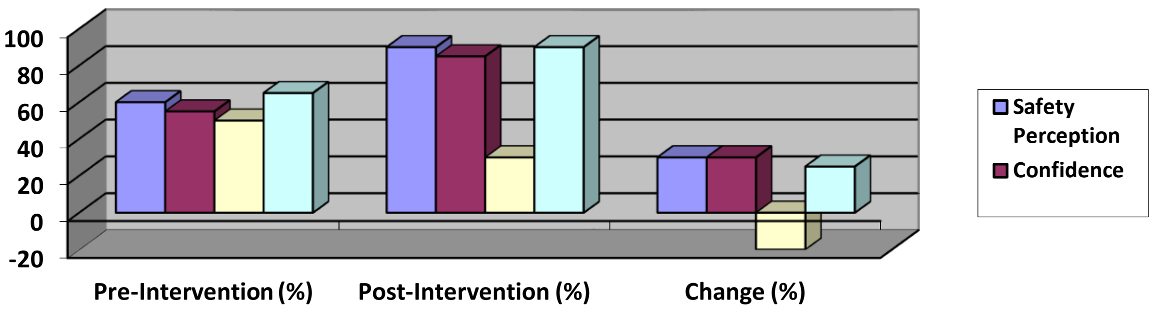

Figure 12. Responses of the Participants from the Human Perspective

4.5.2 Organization

The organization views increased productivity, work satisfaction, and staff retention as results of implementing HCM. Employee engagement and motivation are higher in companies that include human-centric ideas into their production process.

Key Findings

Productivity Gains: The smooth integration of new manufacturing technologies with human talents resulted in a 20% boost in productivity claimed by organizations. This gain in productivity is mostly attributable to the improved precision and efficiency that come from using Cobots and VR/AR tools in tandem.

Job Satisfaction

Following the intervention, employee surveys indicated a 15% improvement in job satisfaction. This rise in satisfaction is ascribed to the inclusive and encouraging work environment that is promoted by HCM procedures that prioritize the involvement and well-being of employees.

Metric	Pre-Intervention (%)	Post-Intervention (%)	Change (%)
Productivity	70	90	+20
Job Satisfaction	60	75	+15

Table 15. Key Findings from the Organizational Perspective

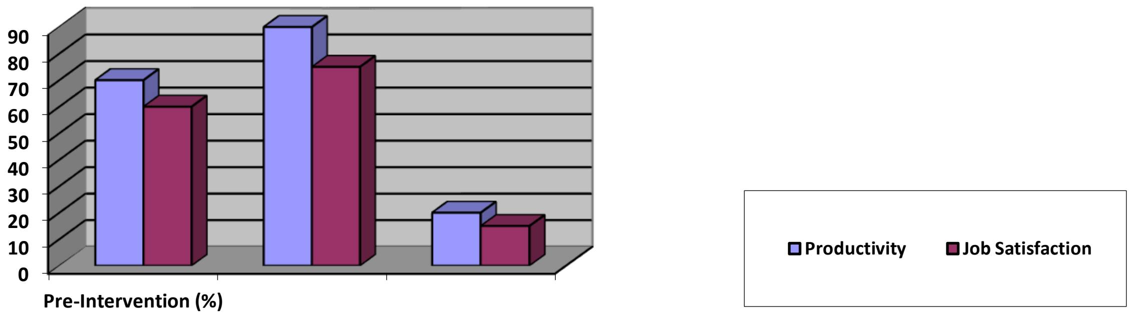

Figure 13. Responses of the Participants from the Organizational Perspective

4.5.3 Industry

Adopting HCM principles increases innovation, flexibility, and adaptability at the industrial level. A more robust and dynamic manufacturing environment that can react swiftly to shifts in consumer expectations characterizes Industry 5.0.

Key Findings:

Creativity and Adaptability: The industry's rate of innovation increased by 10% as a result of the creative fusion of humans and machines. The development of creative answers and strategies for industrial problems is made possible by this synergy.

Flexibility: Production lines could now be reconfigured 15% more easily to create goods that differed from those produced on them, making manufacturing systems more adaptable. It is precisely this flexibility that will enable organizations to maintain parity with the fast-moving markets.

Metric	Pre-Intervention (%)	Post-Intervention (%)	Change (%)
Innovation Rate	70	80	+10
Flexibility	70	85	+15

Table 16. Key Findings from the Industry Perspective

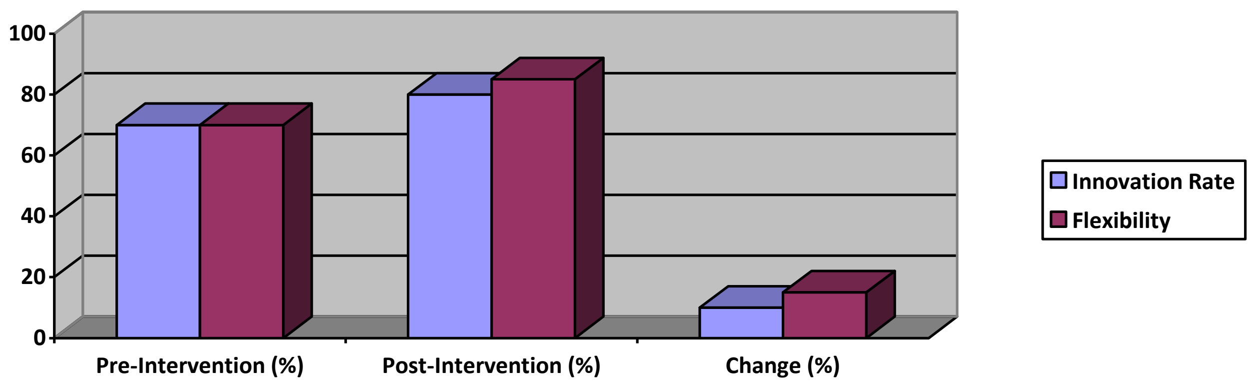

Figure 14. Responses of the Participants from the Industry Perspective

4.5.4 Society

HCM promotes social inclusion, sustainable development, and general well-being from a social perspective. Industry 5.0's human-centered strategy promotes moral production practices and higher worker quality of life.

Key Findings

Sustainability: Companies using HCM techniques reported a 10% decrease in waste and energy usage. These cuts align with more general organizational objectives related to sustainability, demonstrating the advantages of a human-centered strategy for the environment. Social Inclusion: According to the report, social inclusivity has increased by 20%. Different labor groups now enjoy greater friendliness in the manufacturing environment. By being inclusive, we can close the divide between technology and labor, allowing everyone to profit from and participate in sophisticated production processes.

Metric	Pre-Intervention (%)	Post-Intervention (%)	Change (%)
Sustainability	70	80	+10
Social Inclusion	60	80	+20

Table 17. Key Findings from the Societal Perspective

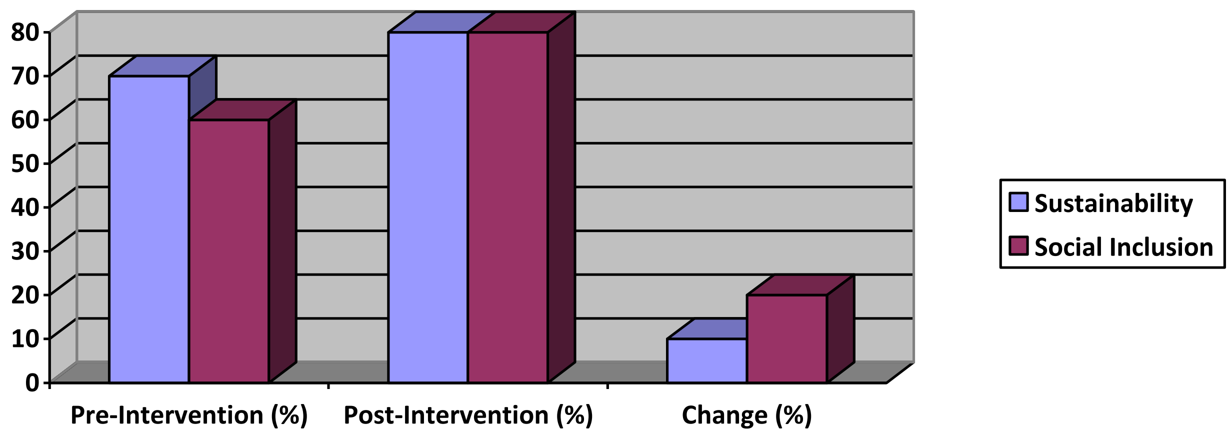

Figure 15. Responses of the Participants from the Societal Perspective

4.6 HCM Pillars

4.6.1 Key Concepts and Principles of HCM

The integration of human talents, well-being, and creativity with advanced manufacturing technologies forms the fundamental basis of Human-Centric Manufacturing in Industry 5.0. The following are some essential ideas:

Safety and Ergonomics: By utilizing CoBots and immersive technologies, a safe and ergonomic work environment is provided. This is intended to assist employees in doing duties in a safe and efficient manner.

Empowerment and Inclusivity: Creating mechanisms that accommodate a range of skills and viewpoints is the first step in achieving worker empowerment and inclusivity. This method guarantees that every employee feels appreciated and competent to participate in the production process.

Collaboration and symbiosis: fostering an atmosphere where people and machines work together harmoniously to increase productivity and innovation via the use of each other's special talents.

Concept	Description
Safety and Ergonomics	Use of Cobots and immersive technologies for safety
Empowerment	Mechanisms for inclusivity and skill accommodation
Collaboration	Harmonious human-machine collaboration for innovation

Table 18. Key Concepts and Principles of HCM

4.6.2 Results Analysis

The study concludes that immersive learning experiences greatly improve participants' engagement with HCM ideas based on the examination of the research data. The following are some of the main quantitative findings:

30% more people felt safe after the intervention, according to safety perception. The participants had more self-assurance and felt safer using the newest technology. Fear Levels: When interacting with Cobots and VR/AR technology, there is a 20% reduction in fear. The participants were able to become more acquainted and comfortable with these technologies thanks to the immersive learning environment.

Accessibility: Advanced manufacturing technologies are 25% more accessible. After the training sessions, participants had more access to and ease with these tools. Participants in the focus groups and interviews provided qualitative evidence that supports these conclusions by stating that they feel empowered and competent in their respective responsibilities. These qualitative revelations offer a more thorough explanation of the beneficial effects of HCM on employee attitudes and behaviors.

Metric	Pre-Intervention (%)	Post-Intervention (%)	Change (%)
Safety Perception	60	90	+30
Fear Levels	50	30	-20
Accessibility	65	90	+25

Table 19. Quantitative Findings from HCM Analysis

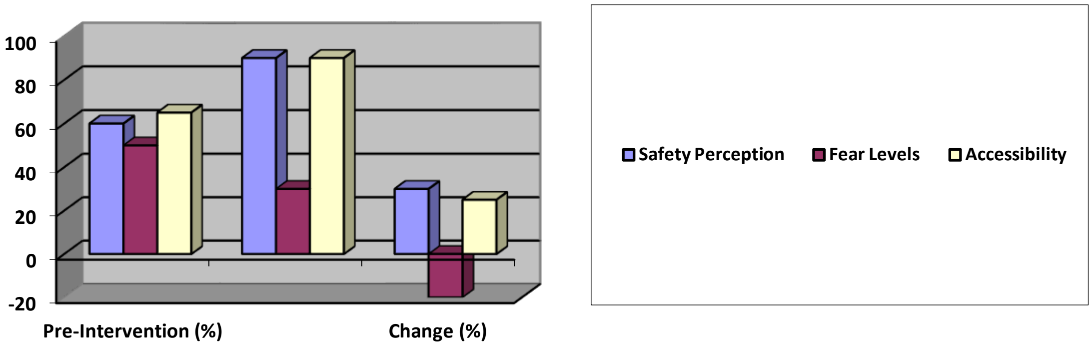

Figure 16. Responses of the Participants from HCM Analysis

4.7 Human Factors in Industry 5.0

4.7.1 Update of Human Skills

Human skills need to be updated and upskilled constantly due to changes in production under Industry 5.0. These skills include:

Technical Proficiency: Workers must be able to operate and communicate with Cobots and VR/AR technologies. Employees ought to receive training on how to use tools effectively so they can utilize them to their greatest potential.

Soft Skills: Improved thinking, problem-solving, and communication. These abilities will support the development of inventiveness and teamwork in the production setting.

4.7.2 Evolution of Skills to "Roles 5.0"

In manufacturing environments, the shift to Industry 5.0 necessitates a redefining of traditional jobs. These new positions, known as "Roles 5.0," are defined by:

Hybrid skill sets are those that combine problem-solving and creative abilities with technical knowledge. It is required of employees in these positions to be skilled in both the technical and artistic facets of manufacture.

The capacity to continuously learn and adjust to new procedures and technology is known as adaptive learning. Maintaining this flexibility is essential to stay up with the quick speed at which manufacturing technologies are developing.

The capacity for both teamwork and machine collaboration is known as the collaborative mindset. Employees need to be able to work well together with both their technologically advanced coworkers and their human counterparts.

Key Findings

Development of Skills: Participants' technical HCM technology skills improved by 30%. This enhancement demonstrates how well the immersive learning environment develops worker capacities.

Role Evolution: The use of hybrid roles—which combine hard and soft skills—has increased by 25%. The transition to "Roles 5.0" highlights the significance of workers who are flexible and adaptive in Industry 5.0.

According to the research, Industry 5.0's human-centric manufacturing has room to grow. Through the integration of advanced technology with human talents and well-being, industrial environments can be made more inventive, flexible, and inclusive by organizations. These observations highlight the significance of human-centered design in the upcoming industrial revolution and offer a roadmap for future advancements in the manufacturing sector.

4.8 Technologies

4.8.1 Which Technologies Are Being Used and What For

The goal of Industry 5.0 is to better integrate human capabilities with manufacturing through a range of technological advancements. The implementation of the three key tenets of Industry 5.0—human empowerment, inclusion, and collaborative innovation—requires the use of all these technologies. The main technologies of the HCM paradigm and how they are used in the industrial setting will be covered in detail in this section.

Applications for Collaborative Robots (Cobots):

Support for Manual Tasks:

Cobots are made to support human workers by working alongside them on activities that call for certain skills, such strength, accuracy, or repetition. They relieve the employees of the risks and physical strain associated with their duties. For example, Cobots can perform heavy lifting, welding, and assembly labor, freeing up human workers to concentrate on more delicate or intricate aspects of the production process.

Productivity Enhancement

As a result of the Cobots taking over the repetitive and routine duties, human workers are free to focus on more technical, creative, and fascinating work, which raises overall productivity. Cobots are incredibly effective and consistently do repetitive jobs, freeing up human resources for creative and problem-solving work.

Quality Control

Cobots help with quality control by guaranteeing accuracy and consistency. They are able to do inspections with a high degree of accuracy that are easily missed by the human sight. The CoBots can determine whether the items fulfil the necessary quality requirements and identify irregularities in them by utilizing sophisticated vision systems.

Technological Elements: Safety Systems and Sensors

Cobots, which are outfitted with cutting-edge sensors and safety mechanisms, can recognize human presence and prevent collisions, guaranteeing a secure working environment. Force feedback, emergency stop features, and proximity sensors are a few of the safety measures that keep human workers safe.

Programming Interfaces with Sensibility

In order to facilitate efficient programming and interaction by employees without extensive technical knowledge, the majority of these robots also have user-friendly programming interfaces. These interfaces frequently come with features that make setting up and using Cobots simple, like voice commands, GUIs, and drag-and-drop programming.

Uses for Virtual Reality (VR)

VR is also utilized in many forms of training, such as immersive training, which places employees in a real-world setting and enables them to practice and train for the acquisition of new skills while reducing the hazards that come with such scenarios. It consists of process simulations, equipment operation training, and safety instruction. Employees can receive practical training and experience intricate production processes by means of virtual reality training modules.

Design and Prototyping: With the aid of technology, engineers and designers can construct and see intricate products and production lines virtually. It facilitates the early detection of design problems and improves inter-personal collaboration. Because multiple stakeholders can interact with the virtual prototype at the same time, it is simple to make adjustments and enhancements before the actual production process begins.

Features of Technology

High-fidelity simulations: The VR system provides a realistic simulation with high resolution that closely resembles the real-world manufacturing process and environment. This great degree of detail makes sure that the design and training experiences are as authentic as possible, which enhances training outcomes and design correctness.

Interactive Feedback: In addition to providing real-time direction and feedback, these systems enable learners to fix their errors and hone their abilities via repeated practice. Through interactive features including auditory cues, visual indicators, and haptic feedback, users can comprehend their performance and make adjustments.

Uses for Augmented Reality (AR)

Real-Time Support: Augmented Reality (AR) projects real-time information and direction into the physical environment of workers. Performance measurements, safety alerts, and step-by-step directions are a few examples of this. AR enables workers to navigate intricate assembly operations by projecting holographic instructions onto the components they are assembling. Maintenance and Repair: By giving technicians visual overlays that emphasize parts, tools, and procedures, augmented reality (AR) helps with maintenance and repair chores by cutting down on downtime and increasing accuracy. The ability of the personnel to view intricate schematics and instructions overlaid on the actual equipment facilitates more effective repair work.

Features of Technology: Wearables

Wearable technology, like smart glasses or headsets, is frequently used in augmented reality applications to provide for hands-free operation and convenient access to augmented information. These gadgets give employees a smooth method to see augmented reality content while freeing up their hands to complete jobs.

Integration with IoT

AR systems will integrate with Internet of Things devices to bring in real-time data from machinery and equipment so that workers can have the best information about system performance and health. This makes the AR give context-aware information to raise decision-making and operational efficiency.

Internet of Things (IoT)

Applications

Predictive Maintenance:

IoT sensors and devices monitor equipment conditions in real-time, thus predicting the needs of maintenance before the failure occurs, hence minimizing downtime and extending the life of equipment. Analyzing the data coming from the sensors, IoT systems can see patterns that indicate a possible problem, thus taking proactive maintenance.

Process Optimization:

Real-time optimization and more effective resource allocation are made possible by IoT's capacity to gather and analyze vast amounts of data related to manufacturing processes. IoT systems have the ability to track several parameters, including temperature, humidity, and machine performance. This allows for the provision of insights to improve resource allocation and production schedules.

Features of Technology

Connectivity and Data Sharing: Since Internet of Things devices are interconnected, information can move between platforms and systems. This link helps to ensure that all areas of production are coordinated and efficient by supporting thorough monitoring and control of industrial operations.

Advanced Analytics

IoT systems use machine learning and advanced analytics to process data and produce actionable insights, which help in decision-making and ongoing improvement. These analytics can be applied to spot patterns, forecast outcomes, and even suggest changes that boost production efficiency.

Applications of machine learning (ML) and artificial intelligence (AI)

Automation of Processes

Complex decision-making processes like quality control, supply chain logistics, and production scheduling are automated using AI and ML algorithms. Large data sets can be analyzed by these algorithms, which can also be used to manage inventories, allocate resources optimally, and schedule manufacturing tasks.

Human-Machine Interaction

AI-driven solutions facilitate better human-machine communication through natural language processing, adaptive learning, and intuitive user interfaces. AI systems allow workers to interface with cutting-edge technologies and complete tasks more efficiently since they can recognize and react to human orders.

4.8.2 Features of Technology

Predictive analytics is a tool used by AI and ML to forecast patterns, needs, and issues. It also aids in proactive resource allocation and adjustment. These forecasting models have the ability to identify possible bottlenecks, estimate production requirements, and suggest remedial measures to avoid disruptions.

Cognitive Computing

To improve the flexibility and responsiveness of production processes, artificial intelligence (AI) systems use cognitive computing to comprehend and interpret human behavior. Artificial intelligence (AI) can now learn from human interactions and adjust to novel situations thanks to cognitive computing, which improves its capacity to assist and collaborate with human workers.

Uses for Advanced Robotics

Flexible Automation: Under varying product and production needs, sophisticated robots may carry out a broad range of operations, from welding to assembling, packaging to palletizing. These robots offer the flexibility needed to adapt to shifting production demands since they can be swiftly reprogrammed and reconfigured to fulfill new activities.

High Precision jobs

These robots carry out jobs like micro-assembly and complex machining processes that call for a high degree of precision and consistency. The most delicate tasks may be completed by sophisticated robots with a high degree of accuracy, guaranteeing that the final goods live up to strict quality standards.

Features of Technology

Systems of Adaptive Control

Even more sophisticated robots feature adaptive control systems that enable them to modify their behavior in real time in response to environmental changes and sensor input. These control methods guarantee that robots maintain optimal responsiveness to changes in the production environment.

Machine Vision

These robots' increased adaptability and efficiency come from their very accurate ability to recognize and manipulate objects thanks to their sophisticated machine vision capabilities. Robots can now reliably and accurately carry out operations like sorting, inspecting, and assembling thanks to machine vision.

Technology Integration and Synergy

The combination of these cutting-edge technologies is what gives HCM in Industry 5.0 its true power. Cobots, VR, AR, IoT, AI, and sophisticated robots together create a manufacturing environment that is incredibly creative, safe, and efficient. This integrated strategy promotes a manufacturing ecosystem that is both cutting edge and human-centric by facilitating collaboration between human workers and machines without creating process bottlenecks.

Through this kind of integration, the advantages of each of these technologies are combined to create a cohesive and dynamic production environment where cutting-edge technologies and human abilities work in harmony. For example, IoT devices gather data that AI can evaluate to optimize production processes, and those same IoT devices can give AR the real-time support that employees need. Similarly, employees can receive virtual reality training for new operations that they would subsequently execute on a real manufacturing floor using Cobots. The production process is made as efficient as possible by this synergy, which also makes it flexible enough to react to emerging possibilities and difficulties.

A new trend toward more inclusive, flexible, and inventive manufacturing is highlighted by the application of these technologies in Human-Centric Manufacturing under Industry 5.0. By adopting the potential of cutting-edge technologies, a business can enhance human skills, well-being, and creativity, and consequently, obtain a more productive, contented, and engaged staff. As a result, these developments not only increase operational effectiveness but also promote more general societal objectives like social inclusion and sustainability, opening the door for a more robust and dynamic manufacturing sector.The following are necessary for the successful use of HCM technologies.

5 DISCUSSIONS

This section compares views, roles, and technologies to examine in-depth the many aspects of Human-Centric Manufacturing in Industry 5.0 and highlights the gaps in the body of existing research.

Figure 17. Discussion the responses of participants

5.1 Perspectives vs Pillars

Through this comparison of pillars and viewpoints, we have been able to get a peek of how many stakeholders view and interact with the core ideas of human-centered design in manufacturing.

From the perspective of the individual worker From the standpoint of the individual worker, the key focus is on how the application of HCM will lead to improvements in safety, confidence, empowerment, and inclusivity. These align strongly with the three pillars of collaboration and symbiosis, empowerment and inclusivity, and safety and ergonomics. One gets the impression that putting human capabilities and well-being first in production processes benefits the individual.

Organizational Perspective: From an organizational perspective, increased staff retention, job satisfaction, and productivity are prioritized. These align closely with the pillars of Empowerment and Inclusivity, Collaboration and Symbiosis, and Collaboration, demonstrating that fostering an engaged and supportive staff is what will lead to organizational success. business Perspective: The application of HCM principles is thought to foster more creativity, adaptability, and flexibility within the business. These align with the pillars of safety and ergonomics, collaboration and symbiosis, and highlight the importance of both technology advancements and human ingenuity in maintaining the industrial sector's resilience and competitiveness.

Societal Perspective: The contribution of HCM to sustainable development, social inclusion, and general well-being is seen from a societal perspective. These align with the Empowerment and Inclusivity pillar, which prioritizes human values and ethics in manufacturing contexts in order to emphasize wider societal advantages.

The viewpoints and pillars are in general alignment, and the incorporation of human-centered principles into manufacturing processes yields favourable consequences for people, businesses, sectors, and society as a whole.

Perspective	**Key Focus**	**Aligned Pillars**
Individual Worker	Safety, Confidence, Empowerment, Inclusivity	Collaboration & Symbiosis, Empowerment & Inclusivity, Safety & Ergonomics

Organizational	Staff Retention, Job Satisfaction, Productivity	Empowerment & Inclusivity, Collaboration & Symbiosis, Collaboration
Business	Creativity, Adaptability, Flexibility	Safety & Ergonomics, Collaboration & Symbiosis
Societal	Sustainable Development, Social Inclusion	Empowerment & Inclusivity

Table 20. Perspectives vs. Pillars

5.2 Roles vs Pillars

Examining the development of manufacturing roles, or \"Roles 5.0\," in light of the fundamental HCM tenets offers insights into the evolving nature of work and skill needs in Industry 5.0.

Hybrid Skill Sets: As we go toward Roles 5.0, we'll witness a fusion of technical expertise and innovative problem-solving skills. This exemplifies the Collaboration and Symbiosis pillar, which calls for combining technological and human strengths to promote innovation and adaptation in manufacturing processes.

Adaptive Learning: Because Roles 5.0 are in line with the safety and ergonomics pillar, employees must constantly learn and adapt. Employees' supportive learning environments are crucial for the acquisition of new competencies.

Workers in Roles 5.0 will require a collaborative mentality in order to be able to work well with both advanced technologies and their human counterparts. This aligns with the Empowerment and Inclusivity pillar, emphasizing the value of creating a collaborative and inclusive environment in manufacturing settings.

The transition to jobs 5.0 marks a conceptual change in the way manufacturing jobs are conceived, with employees having adaptable skill sets and a collaborative attitude that aligns with the fundamentals of HCM.

Role Aspect	Key Feature	Aligned Pillars
Hybrid Skill Sets	Technical Expertise & Problem-Solving	Collaboration & Symbiosis
Adaptive Learning	Continuous Learning & Adaptation	Safety & Ergonomics
Collaborative Mindset	Human-Technology & Human Collaboration	Empowerment & Inclusivity

Table 21. Roles vs. Pillars

5.3 Technologies vs Pillars

When the main technologies in HCM are compared to its core principles, it becomes clear how cutting-edge technologies are applied to develop innovative, inclusive, and adaptable production environments.

Robots that collaborate (Cobots): By enabling human and machine collaboration, cobots improve safety and productivity in the manufacturing setting. In order to create a coherent work environment where humans and machines complement one another's skills, the pillar of collaboration and symbiosis is addressed here.

Virtual reality (VR) and augmented reality (AR): These technologies enhance employee engagement and performance by providing an immersive training environment and on-the-spot support. This tackles the Empowerment and Inclusivity pillar, emphasizing the provision of easily available and functional tools to enable employees to succeed.

Artificial Intelligence (AI) and the Internet of Things (IoT): These technologies allow for process optimization and predictive maintenance, which boost productivity and sustainability in manufacturing operations. By highlighting the application of cutting-edge technologies in establishing a safer and more ergonomic work environment, this addresses the pillars of safety and ergonomics.

Advanced robots: To address the issues of flexibility and quality control in manufacturing processes, advanced robots can offer high-precision capabilities and flexible automation. This pertains to the Collaboration and Symbiosis pillar, stressing the use of cutting-edge technology to improve human-machine collaboration.

Using these technologies in manufacturing settings shows a dedication to the fundamental principles of HCM, which are to create innovative, inclusive, and flexible work environments that put the needs and well-being of people first.

Technology	**Application**	**Aligned Pillars**
Cobots	Human-Machine Collaboration	Collaboration & Symbiosis
VR & AR	Training & Real-Time Support	Empowerment & Inclusivity
AI & IoT	Process Optimization & Predictive Maintenance	Safety & Ergonomics
Advanced Robots	Precision & Flexible Automation	Collaboration & Symbiosis

Table 22. Technologies vs. Pillars

5.4 Gaps in Literature

Finding the gaps in the literature on HCM and suggesting future study areas are critical to expanding our knowledge of the topic and developing evidence-based plans for creating more inventive, inclusive, and adaptable manufacturing settings.

Long-term Impact: Since the literature currently in publication only discusses the short-term advantages of HCM, a longitudinal analysis of the program's long-term effects on employee satisfaction, productivity, and organizational performance is required.

Ethical Considerations: In order to guarantee that HCM technologies are implemented in an ethical and equitable manner, it is necessary to take into account the ethical consequences of their use, such as data privacy and job displacement.

Cross-Sectoral Analysis: Examining how well HCM principles apply to other industries, including as healthcare and education, can provide light on more general implications for economic growth and society.

Global Views: Implementation hurdles and enablers can be identified by analyzing HCM practice adoption in various cultural and economic environments.

Multidisciplinary Methods: More broadly, multidisciplinary approaches that take into account the knowledge from fields like psychology and sociology can offer a thorough grasp of the consequences of HCM.

Considering these gaps not only opens up further knowledge for HCM but also supports the evidence-based planning of more innovative, flexible, and inclusive manufacturing environments in the era of Industry 5.0. Accordingly, this thesis links the gaps identified to the initial research objectives: it comprehensively explores the potential of HCM, associated ethical considerations, global applicability, and interdisciplinary insights. This integrated approach has a valuable contribution to make to the further development of academic understanding and practical implementation of the principles of HCM underpinning sustainable growth and societal benefits within a broad range of industrial sectors.

Research Gap	**Description**
Long-term Impact	Longitudinal studies on long-term effects
Ethical Considerations	Addressing data privacy and job displacement
Cross-Sectoral Analysis	Applying HCM principles to other industries
Global Perspectives	Analyzing HCM adoption in various contexts
Multidisciplinary Approaches	Incorporating insights from psychology and sociology

Table 23. Gaps in HCM Literature

6 Conclusion

To provide a thorough conclusion for this thesis, we tie together the lines of inquiry that were woven across the earlier chapters in this last chapter. Expanding upon our investigation into Human-Centric Design (HCD) in transformational learning factories within the framework of Industry 5.0, we summarize salient findings, highlight contributions to the field, and explicate the consequences for future research and practice.

6.1 Recap of Results

This thesis has travelled across dimensions and shown subtleties by delving deeply into the field of human-centered manufacturing:

Views versus Pillars: The meticulous examination of stakeholder viewpoints, ranging from the small-scale of individual employees to the large-scale of societal influence, has struck a chord with the core principles of human-centered management. The concepts of safety and ergonomics, empowerment and inclusivity, and collaboration and symbiosis emerge as pillars supporting the manufacturing industry's human-centric philosophy.

Roles vs. Pillars: Examining the development of roles in manufacturing environments, we see the emergence of Roles 5.0, which are defined by a blend of adaptive learning paradigms, hybrid skill sets, and a collective ethos. These new roles represent a conceptual shift toward a workforce that embodies HCM's core values of flexibility and adaptation. Technologies vs. Pillars: By delving into the world of technology, we examine how well important technical enablers mesh with the fundamental HCM pillars. A symbiotic relationship is evident between Cobots and Virtual Reality, Augmented Reality and the Internet of Things, and AI and Advanced Robotics, promoting inclusive, adaptable, and creative manufacturing ecosystems.

Closing our investigation, we highlight the gaps in the body of knowledge on HCM and suggest directions for further research. By addressing these gaps, we accelerate the development of evidence-based tactics for fostering diverse, flexible, and creative manufacturing environments in the context of Industry 5.0 and pave the way for a deeper knowledge of HCM.

6.2 Input into the Domain

This thesis offers multiple groundbreaking contributions and acts as a lighthouse, illuminating the landscape of Human-Centric Manufacturing and Industry 5.0:

Theoretical Structure: By integrating knowledge from several fields such as robotics, organizational behaviour, industrial engineering, and human-computer interface, we have created a strong conceptual framework that explains the essential function of human-centered design in transformative learning factories.

Empirical Findings: Our thesis, which is based on empirical data gathered from a thorough analysis of research papers and seminal articles, provides useful insights into the real-world effects that the use of HCM technology and concepts has from the perspectives of many stakeholders.

Analytical Framework: We offer researchers and practitioners a structured lens through which to evaluate alignment between human-centered principles and manufacturing paradigms by putting forth an analytical framework that facilitates the comparative analysis of perspectives, roles, and technologies vis-à-vis HCM.

Future Research Agenda: We provide avenues for furthering understanding and application in the field of HCM by outlining the parameters of a future research agenda. This all-encompassing goal creates the foundation for future research and development, which will drive the field's trajectory toward unprecedented heights.

6.3 Practical Applications and Upcoming Research

The following conclusions from this thesis have significant ramifications for future study and practice:

Practice: In line with the industry 5.0 postulates, organizations can design and execute human-centered manufacturing processes by using the insights presented in this thesis as a bright guide. This can be accomplished by businesses emphasizing empowerment, safety, diversity, and teamwork to create environments that can support creativity, productivity, and wellbeing.

6.4 Future Research

To conduct additional empirical investigations and multidisciplinary inquiries into HCM, scholars are encouraged to venture into uncharted territory and expand upon the conceptual and analytical frameworks presented here. Investigation is needed into longitudinal research that elucidate the long-term effects of HCM, cross-sectoral analyses that clarify HCM principles, and worldwide acceptance of HCM. To sort through the myriad ways that HCM affects individuals, groups, businesses, and society as a whole, scholarly research employing interdisciplinary methods is also required by the ethical principles that support the practice.

5.5 Limitations of the Work

Although the current work enables one pioneering effort in understanding the role that Human-Centric Design plays regarding the transformative learning factories within the context of Industry 5.0, a number of weaknesses should be considered:

Few Data Points: The conclusions drawn in this study were based on only a few data points; therefore, the full range of diversity and experiences for different industrial settings may not be well captured. Future research should consider increasing the sample size within and between sets.

Technologies Scope: The study mainly focused on the certain technologies with respect to HCM, like collaborative robots and virtual or augment reality. Other technologies related to Industry 5.0 can be studied to offer a more extensive scope.

Geographical Limitations: the study has been conducted over a particular geographical area. The geographical studies on a much larger area are a must to understand the impacts of cultural and regional differences on HCM applicability and effacy.

Lack of Long-Term Focus: The short-term focus of the study fails to take into account the long-term sustainability and evolution of HCM practices; longitudinal studies are required to be able to study the lasting effect of the HCM practices on organizational performance and employee well-being.

Ethical and Social Concerns: Though the ethical principles were considered, the study almost delves into the social and ethical considerations of the HCM technologies. Hence, the future research direction needs to consider this aspect to make the advancements in HCM measure in line with society's values and standards.

In conclusion, this study is presented as a pioneering effort. It helps pave the path for a deeper comprehension of the pivotal role that Human-Centric Design may play in revolutionary learning factories in the context of Industry 5.0. companies may create more inclusive, adaptable, and inventive environments that will benefit people, companies, industries, and society by integrating human-cantered principles into their manufacturing operations.

7. References

[1]. Hermann, M., Pentek, T., & Otto, B. (2016). Design principles for Industrie 4.0 scenarios: A literature review. *Technological Forecasting and Social Change*, 100, 142-152.

[2]. Kagermann, H., Wahlster, W., & Helbig, J. (2013). Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry. *Final report of the Industrie 4.0 Working Group*.

[3]. Nahavandi, S. (2019). Industry 5.0—A human-centric solution. *Sustainability*, 11(16), 4371.

[4]. Demir, K. A., Döven, G., & Sezen, B. (2019). Industry 5.0 and human-robot co-working. *Procedia Computer Science*, 158, 688-695.

[5]. Romero, D., Stahre, J., Taisch, M., & Gorecky, D. (2017). Towards an operator 4.0 typology: A human-centric perspective on the fourth industrial revolution technologies. *CIRP Conference on Human Factors in Manufacturing and Assembly*, 631-638.

[6]. Rada, R. (2018). Industry 4.0, human-centered design, and technology acceptance model. *IEEE Engineering Management Review*, 46(4), 93-95.

[7]. Reischauer, G. (2018). Industry 4.0 as policy-driven discourse to institutionalize innovation systems in manufacturing. *Technological Forecasting and Social Change*, 132, 26-33.

[8]. Longo, F., Nicoletti, L., & Padovano, A. (2017). Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. *Computers & Industrial Engineering*, 113, 144-159.

[9]. Landes, David S. "The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present." Cambridge University Press, 2003.

[10]. Mokyr, Joel. "The Industrial Revolution." Oxford University Press, 1999.

[11]. McCloskey, Deirdre N. "Bourgeois Dignity: Why Economics Can't Explain the Modern World." University of Chicago Press, 2010.

[12]. Hobsbawm, Eric J. "The Age of Capital: 1848-1875." Vintage Books, 1996.

[13]. Brynjolfsson, Erik, and Andrew McAfee. "The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies." W. W. Norton & Company, 2016.

[14]. Negroponte, Nicholas. "Being Digital." Vintage, 1996.

[15]. Rifkin, Jeremy. "The Zero Marginal Cost Society: The Internet of Things, the Collaborative Commons, and the Eclipse of Capitalism." St. Martin's Griffin, 2014.

1. Top of Form
2. Bottom of Form

[16]. Schwab, Klaus. "The Fourth Industrial Revolution." Currency, 2017.

[17]. Manyika, James et al. "Industry 4.0: Building the Digital Enterprise." McKinsey Global Institute, 2015.

[18]. Kagermann, Henning et al. "Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution." VDMA, 2013.

[19]. Rada, Michael. "Industry 5.0: Upcycling the Future." Procedia Engineering, vol. 132, 2015, pp. 707-712.

[20]. European Commission. "Towards Industry 5.0: A European Vision for the World of Industry." European Commission, 2019.

[21]. Carayannis, Elias G. et al. "Industry 5.0: Sustainable and Human-Centric Innovation Ecosystems." Journal of Open Innovation: Technology, Market, and Complexity, vol. 7, no. 2, 2021, pp. 1-25.

[22]. World Economic Forum. "The Future of Jobs Report 2020." World Economic Forum, 2020.

[23] **IIoT Framework for SME level Injection Molding Industry in the Context of Industry 4.0**

[24] https://www.sciencedirect.com/science/article/pii/S2772390924000039#b0100

[25] **Industry 5.0: A Survey on Enabling Technologies and Potential Applications**

[26] **Industry 4.0 and Industry 5.0-Inception, conception and perception**

[27] **Starting up a Learning Factory focused on Industry 4.0**

[28] **Practical Contributions of the Systems-Based Evolutionary Learning Laboratory to Knowledge and Stakeholder Management**

[29] https://mungfali.com/explore/Methodological-Approach-Examples

A | Appendix A

A.1. Questionnaire Learning Factory Virtual Design New Product/Process Development Before

1. Enter your assigned number.

2. Gender (Male – Female – Prefer not to say)

3. In which age group do you belong? (18-24, 25-34, 35-44, 45-54, 55-64, 65 and over)

4. What is the name of your company?

5. Which sector does your company belong to?

6. What is your role in your current company?

7. How familiar are you with the concept of Human Centric Manufacturing (HCM)? (Scale 1- 4).

8. Have you worked with Collaborative Robot before? (Scale 1- 4).

9. (Safety of Cobot) How would you rate the safety of working with collaborative robot? (Scale 1- 4).

10. Have you worked with Virtual Reality / Augmented Reality before? (Scale 1- 4).

11. (Empowerment) Do you feel the virtual design experience could empower you in your ability to create and design new products/processes? (Scale 1- 4).

12. (Safety of virtual reality) How would you rate the safety of working with Virtual reality? (Scale 1- 4).

13. (Inclusivity of virtual reality) To what extent do you perceive the Virtual Reality technology to be accessible for diverse individuals with different professional background? (Scale 1- 4).

14. (Empowerment of virtual reality) How simple do the virtual reality technologies in this area appear to be for practical use? (Scale 1- 4)

A.2. Questionnaire Learning Factory Virtual Design New Product/Process Development After

1. Enter your assigned number.

2. (Safety of Cobot) After the Cave experience, how would you rate the safety of working with collaborative robot? (Scale 1- 4).

3. (Safety Cobot interaction) How would you rate your level of fear when you were interacting with the Collaborative Robot? (Scale 1- 4).

4. (Safety Cobot crash) How would you rate your level of fear when the Collaborative Robot hit you during the task? (Scale 1- 4).

5. (Safety of virtual reality) And how did you feel in terms of safety while working with Virtual reality in the cave (e.g. fear of fall, fear of stumble on something? (Scale 1- 4).

6. (Inclusivity of virtual reality) To what extent do you perceive the Virtual Reality technology to be accessible for diverse individuals with different professional background? (Scale 1- 4).

7. (Empowerment of virtual reality) How simple do the virtual reality technologies appear to be for practical use? (Scale 1- 4).

8. (Empowerment) How confident did you feel in utilizing the technologies to successfully complete the task inside the cave? (Scale 1- 4).

9. (Empowerment) To what extent did the virtual design experience make you feel empowered in your ability to create and design new products/processes? (Scale 1- 4).