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TOPICAL REVIEW

Industry 5.0 in Smart Education: Concepts, Applications, Challenges, Opportunities, and Future Directions

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ABSTRACT Industry 5.0 is one of the emerging stages of industrialization in which humans collaborate with cutting-edge technologies to enhance various workplace processes. The primary objective is to emphasize meeting the needs of people and provide enhanced resilience and understanding of sustainability. Industry 5.0 enables cooperation with such advanced technologies and the stakeholders in the education sector to ensure efficiency and effectiveness in the teaching-learning process. The present study provides an exhaustive review of the role of Industry 5.0 in smart education. At the outset, a brief overview of the present scenario in the education sector and its associated challenges is presented. This sets the stage for establishing the need for Education 1.0 and its progressive transition to Education 4.0. Further, the motivation to integrate Industry 5.0 with Education 4.0 and the related enabling technologies that support are discussed. The paper extensively provides a description of the application of Industry 5.0 in various educational sectors namely in medical education, further learning, distance education, engineering education, and shop floor training. The study also presents seven case studies highlighting the successful implementation of Industry 5.0 in versatile sectors and regions. Finally, the challenges of Industry 5.0 in education are discussed pointing to potential future directions of research.

INDEX TERMS Education, industry 5.0, smart education.

I. INTRODUCTION

Education is a fundamental human right, a catalyst for the growth of an individual, and one of the most effective means of eradicating poverty and advancing gender equality, health, peace, and stability. It is the most crucial element to ensure equity and inclusion and produce significant, consistent returns in terms of income [1]. Individuals benefit from education in terms of work, income, health, and poverty reduction. Statistics reveal that with the progression in years of education, hourly earnings also increase by 9% globally [2]. Thus in society, education initiates teamwork, brings new ideas, makes organizations strong, and helps create long-term economic prosperity [3].

The education system incorporates the prevailing policies, structures, practices, and institutions that control education in a specific region or country. It comprises a wide range of components like childhood education, primary and secondary education, higher education, vocational education and training, development in curriculum, methods of examination, and educational governance [4].

The present education system emphasizes developing the Intelligent Quotient (IQ). This is a measure of our intelligence, which includes our knowledge, problem-solving

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skills, visual-spatial abilities, memory, and logical thinking [5]. But with the rise of Artificial Intelligence (AI) and augmented intelligence, these human skills lose prominence. Just having a good IQ is not enough to meet the needs of our society and workplaces. So, to bring out the best in students, not just IQ, but also emotional intelligence and resilience are required [2].

The current education system has been successful in different ways. The current education system has provided universal access to education. The use of technology has revolutionized teaching and learning methods. There is a substantial increase in literacy rates worldwide even in remote areas. The grading process in the current education system tests students not just based on their learning abilities but also their acquired knowledge, skills, and performance in extracurricular activities [6].

However, despite these successes, there are still areas in the education sector that require attention and improvement. Although the current education system includes sophisticated pedagogical techniques and approaches, unfortunately, it lacks the ability to fuel curiosity in students' minds, which could further help them pursue their interests [7]. Students often hesitate to raise their voices on issues pertaining to the existing teaching-learning methods and related processes [8] which further enables them to identify possible reasons for gaps between expectation and reality. The existing system primarily remains confined to the scope of classroom teaching, with the chalkboard system limiting students' interaction within the boundaries of the classroom [9]. Even technology-enabled learning does not fully exploit the possibilities by applying the current state-of-the-art academic experiences. Also, the level of a student's understanding is evaluated based on traditional assessment techniques, which fail to expose their potential in relevant fields of study [10]. The system also fails to address individual student needs and does not provide much space for personalization and inclusivity.

These limitations assumed prominence during the pandemic when the majority of the children and youth experienced learning issues while adapting to the online mode of education [11]. The unexpected pandemic situation acted as a catalyst to worsen the pre-existing global education crisis, impacting almost all levels of the education system [1]. Amid such a pandemic crisis, the education sector has become increasingly dominated by the use of technology, adopting hybrid versions of education wherein digital technologies have been used significantly in association with traditional pedagogical approaches at various education levels. This has minimized in-person interaction, and the technology assisting educators have limitations affecting their decisions [12]. These solutions may seem to provide short-term benefits, but their long-term consequences have yet to be fully understood. It is thus extremely important to use technology integrated with human contact to re-humanize educational services and processes in order to achieve profound long-term impact [13]. This justifies the need to involve Industry 5.0 [14] and related technologies in education, which would ensure effective communication between humans and technologies.

Using Industry 5.0 in education can make a positive impact. It can help us create individuals who are smart, emotionally balanced, and good at social interactions. This can be achieved through its unique teaching and learning methods [15]. Education plays an active role in addressing societal challenges such as resource preservation, and social stability [16], [17]. It empowers employees while also addressing their changing skills and training requirements [18]. The previous tier, Industry 4.0, emerged with the arrival of automation technologies, the Internet of Things (IoT), and smart education. Industry 5.0 takes the next step, which involves leveraging the collaboration between increasingly powerful technologies and the unique creative potential of human beings [19]. Industry 5.0 represents a paradigm shift from digitalization to personalization, where there is the essence of the human touch. Instead of replacing humans, Industry 5.0 will enable the integration of human thinking with intelligent automation, paving the way for Education 5.0.

Education 5.0 would help in emphasizing and prioritizing human qualities at the core of the education system by identifying skills and roles that are most suitable for any individual student. It can help people show their unique talents, boost their creativity, and improve their ability to think critically. It can also help develop their design and problem-solving skills [20]. The focus is not confined to employability alone but also on the needs of society at large. Using Industry 5.0 in education can give a broader view. It can help students understand their learning path, find their place in the job market, and keep up with global changes. In this type of education system, learners are encouraged to be active participants in education and curriculum development [21]. The learners are also guided in the safety and ergonomic aspects of using technologies, thereby ensuring their physical and mental health conditions. Thus, students' abilities and readiness to participate in continuous and lifelong learning are enhanced. A structured comparison between Industry 5.0 technologies in education and alternative approaches or technologies, highlighting the potential advantages and disadvantages of each approach across various aspects such as learning outcomes, cost-effectiveness, accessibility, and integration with the curriculum is presented in Table 1.

A. CONTRIBUTIONS OF THE PAPER

There exists a significant volume of work describing the different enabling technologies and their applications in Industry 5.0. Despite the substantial growth of Industry 5.0 and the understanding of its importance in the education sector, there exists a dearth of exhaustive review articles emphasizing the contribution of Industry 5.0 to education. The present article thus aims to provide a first-of-its-kind review emphasizing the contribution of Industry 5.0 and the relevant enabling technologies in education.

TABLE 1. Comparative Analysis of Industry 5.0 in Education.

Aspect of Comparison	Industry 5.0 in Education	Alternative Approaches/Technologies
Learning Outcomes	• Improved engagement through immersive technologies • Personalized learning paths with AI and ML • Enhanced practical skills with VR simulations • Real-time feedback and assessment with IoT • Access to diverse learning resources via Big Data	• Traditional classroom instruction • Conventional online learning platforms • Textbook-based learning methods • Teacher-led lectures and assessments • Non-technology-based educational resources • Use of analog models or physical materials
Cost-effectiveness	• Potential long-term cost savings with automation • Reduction in paper-based materials and resources • Efficient administrative processes with BC	• Initial investment in technology infrastructure • Maintenance costs of technology platforms • Continuing costs of software licenses and updates • Training and professional development for educators
Accessibility	• Remote learning opportunities with IoT and Cloud • Flexible scheduling and course delivery options • Inclusive learning environments with AR and VR • Access to online educational content anytime and anywhere	• Limited access to technology in certain regions • Dependence on stable internet connectivity • Physical accessibility barriers for certain students • Lack of support for students with disabilities
Integration with Curriculum	• Integration of STEM concepts with real-world applications through Industry 5.0 technologies • Promotion of interdisciplinary learning approaches • Alignment with industry demands and skills	• Traditional curriculum with limited technology focus • Emphasis on theoretical knowledge over practicality • Limited opportunities for cross-disciplinary study • Slow adaptation to emerging technologies • Resistance to change from traditional educational paradigms

In a nutshell, the contributions of our work can be summarized as follows.

- First, we present an overview of the current education system and the role of Industry 5.0 in solving the issues faced by teachers and students in this current education system. We also explain the motivation behind the integration of Industry 5.0 and education.
- Second, we present the literature survey of the concepts of Industry 5.0, smart education, and Industry 5.0 and smart education together.
- Third, we describe in detail the role of Industry 5.0 in education, including the evolution of Industry 5.0 and Education 4.0, and the role of key enabling technologies of Industry 5.0 in education.
- Fourth, we provide details of the applications of Industry 5.0 in various kinds of education fields such as medical education, higher education, manufacturing sector education, distance education, engineering education, and the case studies that are prevalent to date.
- Despite several research and development activities, the associated challenges and issues in the implementation of Industry 5.0 in education are identified. Finally, the potential future research directions towards the integration of Industry 5.0 in education are highlighted.
- We complete the paper with a Conclusion section.

II. RELATED WORK

Various studies have been conducted involving Industry 5.0 and related technologies. The adaptation of Industry 5.0 in any sector requires holistic education transformation. The studies highlighted in this section encompass a range of Industry 5.0-based implementations addressing various aspects and elements of society.

A. LITERATURE REVIEW METHODOLOGY

In this review, a literature survey is chosen to provide an overview of the role of Industry 5.0 in smart education, which includes the following steps. Initially, we highlight the limitations of existing survey papers and the motivations for the integration of Industry 5.0 into Education 4.0. The next step is to search for relevant scientific and research articles on Industry 5.0 for smart education. We focus on high-quality articles that are peer-reviewed in relevant and reputed journals, conferences, symposiums, workshops, and books. The references reviewed in this review are obtained from high-reputed publishers such as IEEE, Elsevier, Wiley, Springer Nature, Taylor & Francis, and other well-known research repositories and archival websites such as Google Scholar and arXiv. Moreover, the following search queries are used to find related references and articles: "Industry 5.0", "Smart education", "Industry 5.0 in education", "Education 4.0", and "Case studies and projects of Industry 5.0 in education" from the aforementioned repositories. Then, we screen all the retrieved papers based on their titles. We have excluded the papers which did not coincide with the scope of the present context. In the next stage, we identify the contributions of the paper by reading the abstract and searching the article for their contributions based on the relevant keywords. In the last stage, we extract the data that is required for our survey on the role of Industry 5.0 in smart education. Table 2 refers to the summary of important Works of Industry 5.0 in Education.

Leng et al. in [26] examined the evolutionary trajectory of Industry 5.0 and highlighted three key traits of Industry 5.0, namely human-centricity, sustainability, and resiliency. The study developed a tri-dimensional system architecture for implementing Industry 5.0 in smart education and explored its important enablers. The current research's shortcomings are reviewed, and the potential future directions of research are highlighted as remarks.

Patil et al. in [14] focused on the key concepts and principles of Industry 5.0. The study concentrates on its techno-socio nature and also elaborates the technological foundations of Industry 5.0 in the form of human-robot correlation, AI and Machine Learning (ML), the internet of everything, Digital Twins(DT), Blockchain(BC), big data, and cloud computing. The core enabling technologies involved in the fifth industrial revolution and the associated challenges of Industry 5.0 in various domains are also discussed.

Grabowska et al.in [22] discussed the key characteristics of Industry 5.0, namely human-machine collaboration, flexible production systems, and their contribution to improving human experiences in the context of industrial operations. The work also uses bibliometric analysis in order to understand the transformation from Industry 4.0 to Industry 5.0. It also emphasizes the materials and methods used in bibliometric analysis and discusses relevant challenges and future directions.

Alves et al. in [19] conducted a thorough systematic review of existing literature pertaining to versatile implementations and aspects of Industry 5.0. The review focused extensively on the key principles, characteristics, and objectives of Industry 5.0 and further explored several ideologies and technologies of Industry 5.0 in the fields of robotics, automation, AI, and IoT.

Panagou et al. in [23] conducted a scoping analysis to understand how the features of robot design have an impact their human counterparts. Almost 32 different articles were reviewed, and the results showed numerous connections between aspects of robot design and how they affect operators. The article concludes by analysing several research gaps and future directions.

Ivanov in [27] focused on the most significant technological features of Industry 5.0 such as coordination, automation, communication, collaboration, identification, and data analytics processing [33]. The four different implementation areas of Industry 5.0 in the form of performance assessment, technology, management, and organization are also discussed. Finally, the open research areas of Industry 5.0 are briefly described.

Coelho et al. in [28] have conducted a bibliographic analysis to understand and analyze the advent of the term "Industry 5.0" when first initiated in scientific literature. The study discusses the need for a more precise definition of the term "Industry 5.0".

Demir in [31] proposed a smart education framework that used various concepts of information technology in its layered architecture. The increasing importance of smart education in the digital age and the potential of technology to transform traditional educational practices are also discussed in the realm of Industry 5.0 and enabling technologies.

Rustiadi in [29] proposed a technique that explored the schools of thought related to the education system. The study discussed concepts of competence-based education and integrated - learning education in the context of Bandung City. The recommendations of the study impacted all stakeholders and enabled the government to improve strategies to further develop their education systems.

Broo et al. in [24] deliberated on the fact that the advent of Industry 5.0 requires a rethinking of engineering education to prepare future engineers to meet the evolving demands of the industry. The key challenges and opportunities in aligning engineering education with Industry 5.0 principles, its role in promoting lifelong learning opportunities for engineers in universities, and industry collaborations were also emphasized in this work.

Ahmad et al. in [25] focused on the dissemination of Massive Open Online Courses (MOOCs) and their evolution in the context of Industry 5.0. The authors presented a roadmap for the future development of MOOC 5.0, which would include strategies for content curation, personalized learning paths, social interaction, and collaboration, assessment and feedback mechanisms, and continuous improvement based on data analytics.

Leelavathi et al. in [30] focused on various application areas of Industry 5.0 namely, banking, healthcare, and education, with the goal of highlighting the contribution of Industry 5.0 to the chosen industries during the COVID-19 pandemic. The study pinpointed relevant support structures

TABLE 2. Summary of important works of Industry 5.0 in education.

Ref No	Education	Use cases and Applications	Enabling Technologies	Future Directions	Remarks
[14]	L	L	H	NA	This study majorly concentrated on development in the socio-economical dimension in the view of Industry 5.0 and less discussion on education.
[22]	M	M	H	NA	The study highlights the need for a balance between technological advancements and human well-being. It proposes Industry 5.0 as a parameter that prioritizes humanization and sustainability in smart industries.
[19]	H	M	M	NA	This systematic review aims to assess the extent to which Industry 5.0 prioritizes human-centric values in its design and implementation.
[23]	M	L	M	M	The authors perform a analysis of 32 articles, exploring the connections between various aspects of robot design and their impact on human operators in industrial settings.
[24]	H	L	M	NA	The study highlights key challenges and opportunities in aligning engineering education with the principles of Industry 5.0. The study also emphasizes the role of universities in promoting lifelong learning for engineers and fostering collaboration with industry.
[25]	H	L	H	NA	The study outlines key strategies for advancing MOOCs, including content curation, personalized learning paths, social interaction, collaboration, assessment and feedback mechanisms, and continuous improvement based on data analytics.
[26]	M	M	L	L	The study discusses the human-centric nature of Industry 5.0. It concentrates majorly on collaboration between humans and machines. It explains the impact of Industry 5.0 on various sectors and considers future directions for research and implementation.
[27]	L	M	NA	L	The study covers details about the perspective of Industry 5.0 through the supply chain model and human-centric ecosystem.
[28]	NA	NA	L	L	The paper mainly focused on the bibliographic analysis of the term Industry 5.0 and its different interpretations in the scientific literature.
[29]	H	NA	NA	L	This research mainly explored the three important schools of thoughts related to the education system as a way to explore how the same issue is addressed in different contexts.
[30]	L	NA	M	L	The paper presents Industry 5.0 as a novel improvement of technologies where healthier communication between humans with machinery takes place. It familiarizes influential technologies for the sustainable, and safe manufacture of goods and services.
[31]	H	M	M	M	The study delved into how to use the framework and design approach to develop a specific course or lecture design. To validate the smart education framework, smart education systems reported in the literature were examined.
[32]	H	NA	NA	M	The paper deals with the vision of Industry 5.0 leading toward Society 5.0.
Our review	H	H	H	H	The review covers Industry 5.0's role in smart education, its applications in education, research and industry case studies, challenges, open issues, and future directions.

H High Coverage: The coverage of the topic is high
M Medium Coverage: The vital aspects and its relation to other topics is discussed partially
L Low Coverage: Very briefly discussed the topic
NA Not Applicable: Did not consider the topic

and services relevant to Industry 5.0 that contributed towards resolving multiple issues during the COVID-19 crisis period. The study further developed a model that illustrated the stages of evolution in each of the chosen sectors, and the contribution of Industry 5.0 to the same is elaborated.

Saxena et al. in [32] focused on the vision of Industry 5.0 leading to Society 5.0. The study identified potential educational possibilities from an ideological perspective and further highlighted the methodology and approaches needed to realize Society 5.0's goals and objectives.

B. ANALYSIS AND CRITICAL DISCUSSION

The summary of the recent works of Industry 5.0 in education is presented in Table 2. The summary table provides a comprehensive overview of various works related to Industry 5.0 in education, highlighting key aspects such as coverage, focus on education, use cases and applications, enabling technologies, future directions, and specific remarks [12]. The color-coded labels (H: High Coverage, M: Medium Coverage, L: Low Coverage, NA: Not Applicable) further assist in understanding the depth of coverage in each work.

The table highlights the lack of comprehensive Industry 5.0 in education analysis in the literature. Most of the Industry 5.0 in education-related publications focused either only on the integration of Industry 5.0 and education but not the use cases and applications and enabling technologies related to their integration. Few technological specifications have mentioned only education alone, Industry 5.0 alone and the integration of education and Industry 5.0 with less details [34]. Similarly, few other publications presented in Table 2 fail to provide a comprehensive analysis of the integration of education and Industry 5.0.

These gaps pave a way for the need of a study that thoroughly investigates the relationship between education and Industry 5.0. The present study aims at covering several aspects like the practical examples, applications and the technologies that make the integration of education and Industry 5.0 possible.

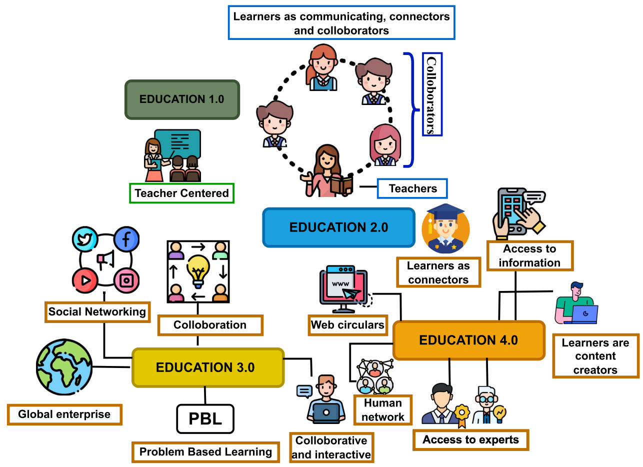

FIGURE 1. Framework of Education 4.0.

III. STATE OF THE ART

In this section, we discuss the evolution of Education 4.0 and Industry 5.0.

A. EDUCATION 4.0

Education 4.0 promotes critical thinking in the classroom. The key component of Education 4.0 is the use of technology-based tools and resources [35]. Education 4.0 not only teaches the students how to utilize textbooks, essay instructors, or pens but it also enables the distant learners to use the internet and sign up for classes through various online courses, video chat facilities, or phone conversations to acquire more dynamic content. Education 4.0 mainly combines information from the real and virtual worlds [36] and incorporates enhanced use of tools and technologies that enable student learning to become faster and smarter.

Intelligent school management systems, Learning Management Systems(LMS), communication tools, and other teaching and learning aids are effectively used in Education 4.0 [37]. Customized learning using Education 4.0 fosters comprehension and provides students access to resources that are genuinely interesting, more professional, and memorable [38]. Education 4.0 is also equally beneficial to teachers, managers, administrators, and students. The four components of education 4.0 are its competencies, learning methods, information and communication technologies, and infrastructure, which act as a reference for the design of new educational innovations [39].

The following are a few noteworthy points related to Education 4.0:

- Education 4.0 enables the automation of administrative tasks for academics, namely enrollment and smart classroom management.
- Being accessible anywhere, Education 4.0 makes education accessible to all students.
- Each student has unique needs and Education 4.0 enables the fulfillment of their personalized educational requirements.
- Education 4.0 promotes industry readiness by introducing students to smart technologies using AI, robotics, and various other technologies.

Evolution from Education 1.0 to Education 4.0 The evolution from Education 1.0 to Education 4.0 indicates the progress of educational methodologies and practices in response to technological advancements and societal changes. Figure 1 discusses the evolution from Education 1.0 to Education 4.0 [40].

Education 1.0: Traditional Teacher-Centered Approach Education 1.0 embodies the traditional model of education with a teacher-centered approach. In this phase, knowledge transmission is primarily one-way, flowing from the teacher to the students. Learning is confined to the classroom environment and relies heavily on textbooks as the main source of information. The emphasis is on rote memorization and adherence to established curriculum standards [41].

Education 2.0: Transition to Interactive Learning Education 2.0 marks the transition to interactive learning methodologies. This phase introduces multimedia resources and technology-enhanced tools to facilitate more engaging and interactive learning experiences. Teachers leverage digital resources such as educational videos, interactive whiteboards, and online simulations to supplement traditional teaching methods. Collaborative learning becomes more prominent, encouraging students to actively participate in discussions and group activities [42].

Education 3.0: Integration of Technology-Enhanced Learning Education 3.0 represents the integration of technology into the learning process on a broader scale. This phase combines traditional classroom instruction with online learning platforms and Learning Management Systems (LMS). Teachers leverage digital tools to deliver content, assess student progress, and provide feedback asynchronously. Students have access to a wealth of online resources, enabling self-paced learning and personalized educational experiences [43].

Education 4.0: Embracing Smart Education Education 4.0 represents the latest phase in the evolution of education, characterized by the widespread adoption of emerging technologies such as Artificial Intelligence (AI), Virtual Reality (VR), Augmented Reality (AR), and Internet of Things (IoT). This phase emphasizes personalized and adaptive learning approaches tailored to individual student needs [44]. Lifelong learning becomes a cornerstone, with flexible and remote learning options enabling continuous skill development and career advancement. The focus shifts towards nurturing critical thinking, problem-solving, creativity, and digital literacy skills essential for success in the modern workforce [45].

B. INDUSTRY 5.0

Industry 5.0 is the new phase in the evolution of industries. It is built upon the advancements of Industry 4.0 and emphasizes the integration of human capabilities and advanced technologies in order to achieve higher productivity, innovation, and sustainability [46]. Unlike its predecessor, which focused on automation and machine-to-machine communication, Industry 5.0 recognizes the importance of human creativity, cognitive thinking, skills, and decision-making [47].

Evolution from Industry 1.0 to Industry 5.0 More than 80% of the world's population worked in agriculture prior to the First Industrial Revolution, cultivating the land and making food for themselves and the rest of the world's population [48].

The transition to new industrial techniques utilizing steam was known as the First Industrial Revolution, which started in the United Kingdom and lasted from 1760 until 1870 [49]. The standard of human life was improved by the use of machines [50]. Figure 2 refers to the evolution of the Industry from 1.0 to 5.0.

The technological revolution, also known as the Second Industrial Revolution (1870-1914), was largely a period of fast scientific discovery, standardisation, mass manufacturing, and industrialization [51].

In the later phase, i.e., the third Industrial Revolution, the world experienced issues pertaining to the lack of jobs, due to the increase in factory automation [34], [52].

Since the last decade, Industry 4.0, a German initiative, has become a globally recognized term across many countries [53], [54], [55], [56]. The European Commission has announced Industry 5.0, ten years after the introduction of Industry 4.0. Industry 4.0 is thought to be technology-driven, whereas Industry 5.0 is thought to be value-driven [57].

Industry 5.0 denotes the transition from Industry 4.0 to the next innovative industrial advancement. The key reason for the transition from Industry 4.0 to Industry 5.0 can be seen in the goal of making manufacturing sustainable from an economic, environmental, and societal standpoint [58]. This necessitates the development of a circular economy with a focus on human-centric industries. Industry 5.0 is understood to acknowledge the strength of the industrial sector to accomplish social objectives, other than jobs and growth [59].

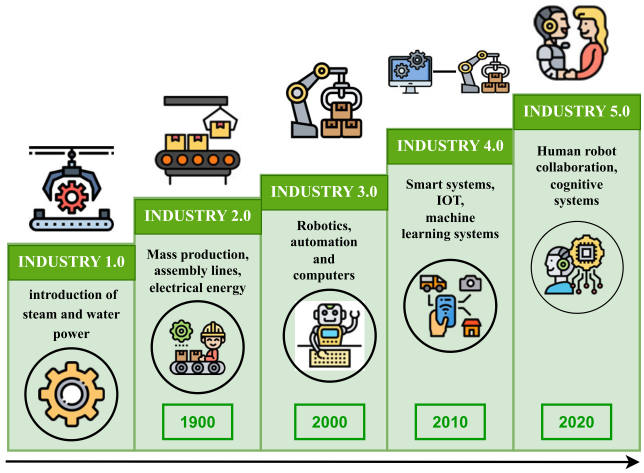

FIGURE 2. Evolution from Industry 1.0 to Industry 5.0.

C. ADOPTION AND INTEGRATION

The adoption of Industry X.0 is intricately linked to industry-specific factors, encompassing characteristics, infrastructure, regulations, and perceived benefits. Industries move at different speeds based on these variations, with technology maturation, economic considerations, and workforce readiness playing pivotal roles. The economic capacity of industries, coupled with workforce skills and training, influences the pace of adoption. The education sector faces the challenge of aligning programs with diverse technological demands. Cross-industry collaboration and agile education models can bridge adoption gaps, while addressing emerging skill requirements is essential [60]. Promoting lifelong learning ensures individuals can adapt to evolving industry practices, irrespective of sector-specific adoption rates.

The evolution of education standards into an industry has seen a transformative journey from Education 1.0 to the recent Education 5.0. This progression aligns with industrial developments, blending traditional and modern tools to create a sophisticated, technology-based education system. The digital transformation in Education 4.0 introduced AI, robotics, ML, and data analytics, fostering an immersive learning environment. The integration of the industrial revolution with the education sector can elevate academic standards to meet global benchmarks. This holistic approach aims to build a future-oriented educational landscape that caters to the dynamic needs of learners and teachers. The industry's influence has modernized academic environments, facilitating knowledge-sharing and innovative ideas through cutting-edge technologies [61]. Figure 3 refers to the transition from Industry 1.0 to Industry 5.0 and Education 1.0 to Education 4.0

IV. MOTIVATION BEHIND INTEGRATION OF INDUSTRY 5.0 IN EDUCATION 4.0

There are several motivations and goals behind the integration of Industry 5.0 and Education 4.0. Education 4.0 is the

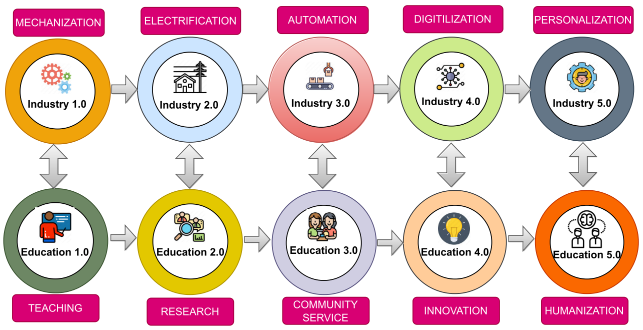

FIGURE 3. Transition from Industry 1.0 to Industry 5.0 and Education 1.0 to Education 4.0.

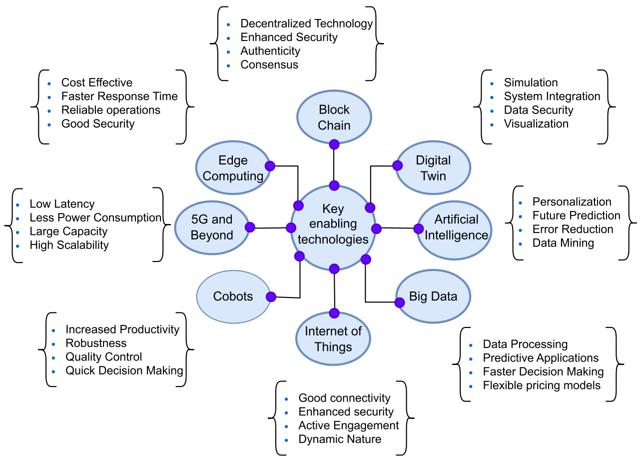

FIGURE 4. key enabling technologies in Industry 5.0 [67].

process of modernization of education with the help of advanced technologies, while Industry 5.0 concentrates on the amalgamation of human intelligence and advanced technologies in several domains. The following list represents a range of motivations behind their integration:

- The integration of Industry 5.0 in Education 4.0 aims to prepare students for the future workforce. Students can acquire the skills and information required to flourish in a job market that is rapidly evolving by integrating industry-relevant technology and practices into the educational system. The objectives of Education 4.0 are aligned with Industry 5.0's emphasis on the value of human creativity, problem-solving, and critical thinking [62].
- Several modern technologies including AI, robotics, and the IoT are being integrated into industrial processes, according to the concept of Industry 5.0. Students can experience real-world uses of these technologies and develop a greater understanding of their usefulness in diverse industrial settings by incorporating Industry 5.0 concepts into Education 4.0. This aids in bridging the knowledge and practical skills gaps [49].
- The combination of Education 4.0 and Industry 5.0 aims at improving learning outcomes by using several advanced technologies. Several technologies such as Augmented Reality (AR) and Virtual Reality(VR) can also be leveraged to create engaging and experimental learning environments. In addition, several other technologies including data analytics and AI can provide personalized learning experiences, adaptive assessments, and intelligent feedback, leading to improved learning outcomes [63].
- Innovation and entrepreneurship are emphasised as major forces behind economic progress in Industry 5.0. Educational institutions can encourage a culture of innovation and entrepreneurship among students by incorporating Industry 5.0 principles into Education 4.0 [15]. Promoting innovation, problem-solving abilities, teamwork, and the capacity to recognise and embrace possibilities in developing industries are all part of this [34].
- The integration of Industry 5.0 in Education 4.0 aims to address the skills gap between the demands of the job market and the skills possessed by graduates. By aligning education with industry needs, educational institutions can help students develop the skills, knowledge, and competencies required in the evolving job market [64]. This helps increase employability and ensures that graduates are well-prepared for the workforce [65].
- Industry 5.0 places a strong emphasis on the necessity of lifelong learning and upskilling. Education 4.0 encourages lifelong learning and offers opportunities for ongoing professional growth when combined with Industry 5.0. Individuals can develop new skills and keep up with the most recent market trends by utilising technology such as online learning platforms, and personalised learning pathways [66].

V. ROLE OF KEY ENABLING TECHNOLOGIES IN INDUSTRY 5.0 IN SMART EDUCATION

Several key enabling technologies such as Big data, IoT, BC, Edge Computing(EC), AR, VR, DT, Cobots, and 6G and beyond when paired with cognitive capabilities and innovation, have immense potential to help education [67].

A. BIG DATA

Big data refers to large volumes of data that are hard to manage, where the data can be either structured or unstructured. Big data is very useful in decision-making and has revolutionized many fields, including education [68].

Big data plays a vital role in enabling education in the context of Industry 5.0. Every educational institution collects large amounts of student data day to day. This data can be analyzed to provide a personalized learning experience and to provide awareness of student engagement and performance [69]. Big data influences curriculum development based on industry needs, and predictive modeling supports educational planning. Big data insights drive efficient resource allocation, continuous improvement, and distance learning. Educational research benefits from large data and thereby promotes competency development [70]. Big data, when integrated with BC, ensures educational records and certifications remain secure. Overall, big data enables educators to make data-driven decisions, improve student learning experiences, and align education with the dynamic demands of Industry 5.0 [71].

As an example, big data can be integrated with LMS to track course material and student interactions, provide real-time feedback, and provide personalized recommendations.

The data in the education sector can be inconsistent, heterogeneous, and sometimes prone to errors. Normalizing and integrating data is complex and time-consuming. Managing and storing large volumes of data is challenging. The use of big data will raise ethical concerns and require good data governance policies [72]. An efficient skill set is needed to use big data effectively. Implementing big data infrastructure, tools, and analytics can be costly.

1) IMPACT ON EDUCATION

The integration of big data in education empowers educators to make data-driven decisions, enhancing student learning experiences. By aligning education with the dynamic demands of Industry 5.0, big data contributes to the continual evolution and improvement of educational practices [73]. Despite challenges, the strategic use of big data promises to reshape education, making it more responsive, personalized, and effective.

Some of the examples of integrating big data analytics in smart education 4.0 in the realm of Industry 5.0 can be visualized in the implementation of student monitoring systems, Automated Student evaluation systems, online learning environments, conducting of national and international surveys and various other applications. In case of student monitoring systems, data can be captured in the form of images or in terms of academic performance and further analysed for predicting students concentration level, identifying distracted students and further detecting root causes of such attention deficiency. Also the predominance of big data have enabled administrative bodies in Universities to take accelerated and accurate decisions to address key challenges pertaining to the ever evolving market conditions. The success of education delivery in the context of Industry 5.0, where universities operate, depends on the effective integration of big data resources. The education delivery models in the Higher Education Institutes are also progressing towards being big-data centric which is considered as their cognatic capability [74].

B. INTERNET OF THINGS

IoT is a network of physical objects, including machinery, automobiles, appliances, and other items, that are equipped with sensors, software, and communication capabilities to collect and exchange data [75].

IoT is one of the key enabling technologies for Industry 5.0 in the field of education. It makes it easier for a variety of devices, sensors, and objects to be connected to one another and integrated into the learning environment. IoT in education makes it possible to gather and analyze real-time data, facilitating the analysis of behaviour, learning patterns, and student performance [76]. IoT assists in transforming traditional teaching methodologies into digital ones, which is an added advantage. It promotes the development of innovative teaching tools and software, makes it easier to personalize and adjust learning experiences, and permits remote and collaborative learning [77].

IoT devices can be deployed in classrooms. For example, smart whiteboards equipped with IoT sensors can provide interactive and dynamic learning experiences [78]. This allows students to collaborate, share content, and access educational resources in real time.

However, the adoption of IoT in education poses a few challenges, including data privacy and security concerns, interoperability issues, and the need for reliable connectivity infrastructure. Overcoming these challenges requires robust policies, standards, and protocols, as well as investments in infrastructure and cybersecurity [79]. When effectively implemented, IoT in education has the potential to revolutionize teaching and learning, creating dynamic, interactive, and customized educational experiences [80].

1) IMPACT ON EDUCATION

When effectively implemented, IoT in education holds the promise of revolutionizing teaching and learning. It introduces dynamic, interactive, and customized educational experiences, fostering an environment where technological advancements enhance the overall learning journey [81]. The ongoing integration of IoT into education is poised to contribute significantly to the evolution of teaching methodologies, promoting accessibility, collaboration, and adaptability.

The role of IoT is enormous for its inclusion in education leading to Education 4.0. The benefits include improvement of learning outcomes, its ability to enhance students' attention and retention capability acting as an aid to support teaching effort. The use of IoT in smart education 4.0 can be visualized in Task-based learning, inclusiveness of disabled students, remote learning, automation and tracking of tasks and resource management. To be more specific, the use of IoT can enable students to collaborate and share knowledge amongst peers effectively leading to better learning outcomes. The use of IoT can enable students and teachers remain connected, get support and assistance at any time enhancing their learning experience. In terms of inclusiveness, the use of IoT have improved on-campus circumstances, enabled specialised instruction, and smooth peer and teacher contact. Hearing impaired students can use automated language translation devices, visually impaired students can use AR, VR and sensor based smart sticks and headsets; smart doors are used for ease of navigation establishing a better learning environment. The use of IoT enabled remote learning tools have fostered global connectivity and cross-cultural exchange rendering flexibility to the students to learn as per their own pace and schedule. As an example, Google classroom, Tynker are tools which are popularly used by academic Institutions in this regard. The IoT enabled tracking systems have facilitated monitoring of the students whereabouts ensuring safety, efficiency and have further provided valuable insights to the teachers.Kajeet is one such application that helps in monitoring of student behaviour. The automation of administrative tasks using such IoT devices have extensively reduced workload of the teachers enabling them to focus on value added academic activities making the system more agile and lean [82].

C. BLOCKCHAIN

BC is a decentralized and distributed digital ledger technology that securely records and verifies transactions across multiple computers [83]. It enables the transparent and immutable storage of data in a way that is resistant to tampering or modification.

BC as an enabling technology of Industry 5.0 where human-centric collaboration is emphasized, can provide significant benefits to the education sector in several ways. BC enables the maintenance of the integrity of the education system by storing the records of academic achievements, certifications and credentials in a tamper-proof manner [84]. BC helps schools and universities to maintain the students' academic performance records securely. These records can be accessed from anywhere. With BC, students progress and outcomes can be tracked over time. This can help educators create personalized and effective learning experiences. Educators can use BC to securely store and share their educational content. BC can also be used to create secure, efficient payment systems for tuition and other fees [85]. This can be of particular benefit to international students undertaking distance learning programs. As an illustration, students can have their degrees, certificates, and diplomas recorded on the BC, and employers or other institutions can instantly verify the authenticity of these credentials without delay [86].

While BC holds promise for transforming education in Industry 5.0, it also faces several challenges. One major challenge is scalability. Scalability problem arise when BC networks become slow and inefficient when processing a large volume of transactions [87]. The energy consumption associated with BC networks is another concern, as it requires significant computational power. Additionally, the complexity of integrating BC into existing educational systems and processes is a challenge, as it requires coordination and collaboration among various stakeholders. Ensuring data privacy and security on a public BC is also a challenge, as sensitive educational information needs to be protected [88]. Moreover, there is a need for standardization and interoperability across different BC platforms to ensure seamless data exchange. Figure 4 discusses the key enabling technologies used in Industry 5.0.

1) IMPACT ON EDUCATION

The utilization of BC in education revolutionizes traditional processes, offering transparency, security, and accessibility. The ability to instantly verify credentials streamlines administrative processes, reduces fraud, and enhances the overall efficiency of educational institutions [89].

D. EDGE COMPUTING

EC is a decentralized computing approach that moves computation and data storage closer to the edge of the network [90]. EC transfers the processing and data management to the devices that are located closer to the end users, termed the edge devices.

EC provides continuous connectivity and communication across various devices and systems in an educational environment. In educational setups where a number of IoT devices and sensors are widely used for collecting different types of student data, EC can handle the enormous amounts of data generated by these devices. This enables the administration to track the student's progress in real-time and personalize the instructional strategies [91]. EC also improves the security and privacy of student data. Sensitive student data such as their personal details, grade information, etc., can be processed locally at the edge, keeping it within the local network and lowering the possibility of data breaches and unauthorized access [24]. EC allows students and teachers to quickly and seamlessly interact in virtual classrooms and improves virtual experiences and learning outcomes.

As an example, consider a classroom that is equipped with several sensors and smart devices that gather student attendance. With EC, the data collected through sensors can be processed locally which eliminates the need to send the data to a cloud server for validation [92]. The edge device can quickly assess the data and provide timely insights.

The integration of EC as an enabling technology of Industry 5.0 in education brings numerous benefits but also has associated challenges. Setting up the necessary infrastructure and connectivity for leveraging EC in the education sector is cost time-consuming process [93]. Also, the integration of EC faces hurdles in ensuring data security and privacy, scalability, and management. This technology also faces problems in integration and interoperability with existing systems and high investment in skills and training [94]. By addressing these challenges using strategic planning, educational institutions can leverage EC to enhance the learning experience and unlock new opportunities in education [95].

1) IMPACT ON EDUCATION

EC in Industry 5.0 may greatly enhance education through improved real-time processing. decreased latency, increased efficiency, improved security, real-time interactions, on-the-spot data analysis, better resource management, and faster access to educational materials are all made possible by it. To improve learning outcomes in connected classrooms, edge devices can also be integrated with IoT devices [96].

Education professionals may save student learning outcomes, credentials, credit management, and other data by utilising blockchain-based solutions. Any data pertaining to an educational institution can be saved and utilised for research and decision-making in the future. The majority of educational institutions worldwide offer certificates in both paper and digital formats. Paper certificates are convenient for recipients to carry, preserve, and display to others for any reason. But obtaining, confirming, and keeping these certifications is a costly and time-consuming procedure. In this context, digital certificates are substitutes for digital signatures, and the entirety of the certificate's proofs can be safely and securely stored in blockchain. The certificates will remain on the blockchain even in the event that the issuing institution closes. The issuing organisations for digital certificates have the option to store the digital signature on a public blockchain. Also multi-step verification can also be performed using blockchain technology to authenticate certificates. If the certificate is uploaded into a blockchain instead of just the digital signature, it will be preserved there forever and cannot be altered. An intermediary is not required to handle the certificates. When it comes to credit transfers, a smart contract can be created so that, should a specific requirement be met, the credits are moved automatically between the two institutions. Teachers can mark the publication and documentation of free educational resources with a blockchain. For copyright reasons, this would necessitate a notary of the publication date and allow for the tracking of how much of a certain piece of property is used again [97].

E. AUGMENTED REALITY

AR is an improved and interactive version of the real world that is achieved through digital visual elements, sounds, and others [98].

AR in education can provide a very engaging medium for students with the capability of changing the system of teaching and learning. AR can make classroom education more interactive and engaging by enabling the teachers to provide virtual examples of the concepts being taught [99]. The virtual example will enable the students to learn faster and memorize concepts and facts more easily. AR can also help in reducing the training costs incurred while enhancing the involvement of the learners [100]. AR makes the learning system more effective through the use of rich visuals and immersion within the subject matter. It allows easy access to the learning materials anywhere and anytime. AR technology has great potential to improve education for students with disabilities. By providing a multi-sensory and interactive learning experience, AR creates an inclusive environment that accommodates different abilities and learning styles. AR also improves orientation skills for visually impaired students while facilitating social interaction and self-directed learning.

As an illustration, AR is used in the medical education field to create virtual anatomical models and simulations. Medical students can manipulate virtual organs, systems, and surgeries to facilitate hands-on learning and understanding of complex medical concepts.

AR shows the potential to transform education in Industry 5.0. However, it also faces major challenges. While the high cost and accessibility of AR devices and content development are hurdles, infrastructure and connectivity issues can hinder AR implementation in regions with limited internet access [101]. Teachers may lack training, and effective incorporation of AR into the curriculum requires careful planning. Privacy issues and technical challenges should be carefully considered. Long-term sustainability, appropriate evaluation methodologies, and support for educators are essential to successfully harnessing the potential of AR in education as Industry 5.0 progresses [102].

1) IMPACT ON EDUCATION

AR significantly improves the effectiveness of teaching and learning by offering a dynamic and interactive medium. Its virtual examples facilitate faster comprehension and retention of concepts, contributing to overall learning efficiency. The inclusivity of AR accommodates diverse learning styles and abilities, particularly benefiting students with disabilities [103]. In the medical education sector, AR enhances hands-on learning experiences, providing a valuable tool for understanding intricate medical concepts. While facing challenges, the educational impact of successfully integrating AR into the curriculum is transformative, offering engaging, inclusive, and effective learning experiences aligned with the goals of Industry 5.0.

One of the industries that benefits most from immersive learning is the medical field. Surgeons can practise difficult surgical methods on a 3D model in a virtual setting using AR and VR technology, without actually operating on patients. In the realm of online learning as well as in education in general, retention rates have always been a problem. AR/VR technology can be used by educators to increase academic achievement and enhance student retention rates, depending on what they are teaching. Virtual reality (VR) presents scientific and engineering topics in an interesting way. Humans are primarily visual learners, which is why VR and AR can increase retention rates. 3M Corporation research indicates that people typically digest images 6,000 times faster than words. Because of this, it is inevitable that learners or students will understand the material more quickly in an immersive setting.

F. VIRTUAL REALITY

VR is a computer-generated, immersive, interactive experience that simulates a three-dimensional environment, often used to recreate real-world environments or create entirely fictional environments [104].

VR is becoming a key technology for education in the context of Industry 5.0. It provides an immersive learning environment where students can experience realistic scenarios and gain hands-on experience in a variety of industries [105]. VR facilitates skill development by providing interactive exercises that improve technical and human-centered skills such as problem-solving and creativity [106]. Additionally, it enables personalized learning that tracks an individual's learning progress and adjusts content accordingly. Through its remote collaboration capabilities, VR connects geographically dispersed students and faculty, facilitating interdisciplinary learning and teamwork. In areas where dangerous or complex training is required, VR offers a safe and cost-effective solution [107]. Enhanced visualizations prepare employees for the evolving demands of Industry 5.0.

For example, medical VR simulations can cover a wide range of scenarios, from basic skills like suturing and injections to complex surgeries and emergencies. VR as an enabling technology for education in Industry 5.0 faces several challenges. High development costs and technical complexity of VR hardware create financial and implementation barriers for educational institutions [108]. Additionally, teachers require training to effectively incorporate VR into their teaching practice. Health and safety concerns, limitations on real-world interactions, and the need for standardized assessment methods further complicate the integration of VR into educational environments [109]. Addressing these challenges is key to unlocking the full potential of VR to enhance learning experiences in Industry 5.0.

1) IMPACT ON EDUCATION

The technical details elucidated for VR underscore its role in revolutionizing education within Industry 5.0. The immersive learning experiences provided by VR enhance skill development, promote personalized learning, and facilitate remote collaboration [110]. The challenges outlined emphasize the importance of addressing barriers to unlock VR's full potential in augmenting learning experiences in Industry 5.0, underscoring the need for strategic solutions and investments in overcoming these impediments.

One excellent example of an organisation using virtual reality in education is Harvard University. The institution provides Computer Science 50 (cs50), an introductory course in computer science, in virtual reality. Even if they are participating from home, students put on their glasses or virtual reality headsets and seem to be seated among their fellow classmates in the middle of the lecture hall. Globally, more than three million students have finished the online course.

It is often difficult for teachers to keep an eye on their students' engagement. VR, however, allows them to unwind and feel secure in the knowledge that the technology can engage learners and thoroughly immerse them. Students can be more interested and creative when using VR and AR with 3D visuals since they can assist stimulate curiosity and imagination. Furthermore, not everyone learns in a language they fully comprehend or in their mother tongue. Understanding what is being taught becomes more challenging when there is a language barrier. Virtual reality has demonstrated its ability to offer a smooth educational experience for those attempting to acquire a second language. Students can comprehend and learn material more quickly due to the VR and AR's ability to translate or transcribe teachers' courses. Students frequently hesitate to talk or ask questions when learning online because they are afraid they may pronounce words or sentences incorrectly. VR can make interactions simpler and more adaptable.

G. DIGITAL TWINS

DT refers to a data flow between a physical entity and a digital entity that is connected in both directions [111].

A DT allows the use of virtual replicas of real-world equipment, which enables the students to conduct experiments and explore very tough concepts in a safe and cost-effective virtual environment [112]. DT enables remote access to physical objects and systems that enable distance learning. Educators can use DT to demonstrate real-world applications of theoretical concepts, making learning more tangible and relevant [113]. It enables the creation of IoT-based smart classrooms, enhancing classroom management and resource allocation. DT can be used in teacher training programs to simulate classroom scenarios and improve instructional skills. It can create a digital replica of the entire educational campus, supporting efficient facility management, resource optimization, and safety protocols [114].

As an illustration, DT can be used to create virtual lab environments, simulate real-world experiments, and enable students to conduct experiments safely and remotely.

DT rely on accurate and up-to-date data to create realistic simulations. Integrating data from various sources and ensuring its accuracy can be challenging. Developing and running DT can require significant computational resources and infrastructure [115]. Building a DT involves creating detailed models that accurately represent the physical system. Developing these models can be complex and time consuming, requiring expertise in areas such as data modeling, physics, engineering, and simulation. Many educational institutions cannot afford the cost of DT setup. DT can involve the collection and utilization of sensitive data. Ensuring the privacy and security of student and institutional data is crucial [116].

1) IMPACT ON EDUCATION

The technical intricacies of DT highlight its transformative potential in education, offering immersive and practical learning experiences. The challenges outlined underscore the need for addressing technical and financial constraints, ensuring the privacy and security of data, and promoting widespread accessibility to fully realize the educational impact of DT in Industry 5.0 [117].

Digital twin technology can be applied in the classroom to facilitate experiential and hands-on learning. With the use of this technology, it would be possible to comprehend a system's structure and modes of operation. A digital twin can be employed in the lab to investigate the limits and behaviour of the system in a variety of simulated scenarios. Students learn and comprehend system behaviour in a simulated, controlled environment more quickly because a digital twin's virtual representation is easier to change than its actual counterpart. Digital twins are essential to action research as well. Students can use the digital twin to run simulations to investigate how a system might behave in various what-if scenarios, comprehend failure mechanisms, and learn how sensitive a system is to changes in different system characteristics and outside disturbances. This knowledge contributes to increasing the system's throughput and reducing downtime. The easiest way to understand the fidelity of a systems model is to use DT in simulation.

H. COBOTS

Collaborative robots are meant for human and robot direct interaction in a shared space or in proximity [118].

Cobots help students in hands-on learning by conducting experiments and practical works, which provide real-time guidance and feedback. The integration of cobots with VR and AR technologies creates an interactive and engaging learning environment for students. They also provide personalized support to students with disabilities [119]. They help them to go through the learning environment and perform tasks. Cobots also foster teamwork, group activities, and collaboration among students. Cobots also perform hazardous tasks, reducing the risk of accidents for students and teachers [120]. Cobots can handle administrative tasks, such as grading assignments, relieving teachers' administrative burden [121].

As an example, to increase student interest and knowledge in robotics and automation technologies, cobots were occasionally displayed at educational fairs, scientific exhibitions, and campus activities.

Cobots need to operate safely alongside humans, particularly in educational settings where students are present. Integrating cobots into educational environments may require modifications or adaptations to existing infrastructure and workflows. Implementing cobots in educational settings can involve significant costs. Operating and maintaining cobots require specialized technical expertise [122]. Cobots raise ethical considerations, including issues of privacy, and data security.

1) IMPACT ON EDUCATION

The technical capabilities of cobots contribute to immersive and engaging hands-on learning experiences, fostering collaboration and inclusivity in educational settings. Recognizing the challenges underscores the importance of addressing safety concerns, providing necessary technical expertise, and navigating ethical considerations to fully realize the educational impact of cobots in Industry 5.0 [123].

Cobots are essential to enhancing the ecosystem of education. They support educators by helping with experiments, assignment grading, and providing students with timely feedback. This means that since cobots do the repetitive chores, teachers can focus on providing individualised education. Cobots resemble educational resources. They enable students to work with contemporary technology and acquire practical skills necessary for employment. Students can learn about robotics, automation, and programming by interacting with cobots. One such example is the Mirobot Professional Kit developed by WLKATA Robotics.It is a versatile cobot designed for enhancing the teaching-learning experience. With a 0.2mm positioning precision, it is lightweight and precise, making it appropriate for a variety of activities. It can be controlled in three different methods, depending on the user's ability level: via a PC, the Mirobot Bluetooth Controller, or a mobile app. Additionally, it includes the Multifunctional Box (Extension Module), which supports Bluetooth, BT, WiFi, and RS485 protocols, to enhance communication. The use of Cobots thus enables enhanced student engagement wherein students actively participate and stay focused. It also helps them to apply the skills learnt to resolve real-life problems making them industry ready. The students efforts in programming and controlling robots enables them to get hands-on learning experiences encouraging critical thinking ability and creativity.

I. 6G AND BEYOND

A fully connected world's requirements are met by 6G and beyond, which provides access to wireless communication [124].

6G offers ultra-fast and reliable connectivity, faster transfer data rates, and higher network capacity than the previous generations. This facilitates seamless communication and instant access to educational resources [125]. 6G provides effective learning experiences with its high-speed and low-latency capabilities. It also facilitates technologies like AR and VR which helps students to engage in real-time experiences. The ubiquitous connectivity of 6G ensures that educational resources and platforms are accessible anytime and anywhere. Students can engage in mobile learning experiences [90]. 6G also enables extensive integration of IoT devices in educational settings. 6G fosters global connectivity, enabling seamless collaboration and knowledge sharing among students, teachers, and experts across geographical boundaries. As educational systems become more interconnected, 6G offers enhanced security features to protect sensitive educational data and ensure privacy [126]. 6G supports education by exploring and integrating emerging technologies.

For example, in labs, 6G networks can provide remote access to laboratory equipment that helps students in distant locations to access and control lab equipment through virtual interfaces.

6G networks that include high-speed connectivity and coverage will cost a lot to build the infrastructure. It takes specialized knowledge to implement and manage these sophisticated technologies, and there may be issues with system integration, interoperability, and compatibility [127]. The affordability and accessibility of 6G-enabled devices and services may be constrained, especially for educational institutions with fewer budgets. In the devices that are interconnected through 6G, privacy and security are the major challenges. It is also difficult to guarantee that all students, regardless of their location and socioeconomic status, have equal access to 6G-enabled education [128]. It is also essential to create proper laws and policies to control 6G technology in educational institutions.

1) IMPACT ON EDUCATION

6G's educational impact is far-reaching, promising to revolutionize teaching and learning experiences. The integration of 6G introduces dynamic, interactive, and customized educational approaches, fostering an environment where technological advancements enhance the overall learning journey [129]. This ongoing integration is poised to significantly contribute to the evolution of teaching methodologies, promoting accessibility, collaboration, and adaptability in education. The of 6G and beyond in Education 4.0 can be visualized in the high quality 360 degree video streaming which has wide applications in class room teaching, engineering education, medical education and any academic sector where virtual classes are conducted. For learners to be completely satisfied with the learning process, the remote setting must be as similar to real physical attendance as possible. This is only achievable with high-quality 360-degree video streaming, which will be viewed through headsets to provide users a real-time, remote environment experience regardless of their location. As an example, the human eye requires 720 million display pixels to focus on both near and far objects, perceive in both high and low light, and have a very wide field of vision—150 degrees horizontally and 120 degrees vertically—all without moving the head. Because of this, one of the most important prerequisites for future education is high resolution 360° video streaming, which will allow for human eye-quality streaming and, consequently, a genuine attendance experience in remote environments.In this sense, the incredibly low latency and large data rates offered by 6G connectivity improve the educational experience. Additionally, it gives students more control in a remote setting when they engage in tele-operation, where strict communication is necessary to guarantee a smooth operation process and robots integration. 6G technologies enable the ultra-low latency, ultra-high dependability, and dedicated bandwidth needed for such real-time control [130].

VI. APPLICATIONS OF INDUSTRY 5.0 AND ITS KEY ENABLING TECHNOLOGIES IN EDUCATION

Industry 5.0 has several applications in the field of education. Also, Industry 5.0 refers to the collaboration of technologies with educators and students to improve the efficiency and effectiveness of teaching and learning. Industry 5.0 technologies can revolutionize the learning and teaching process of students and teachers respectively. The following fields of education are referred to based on a few studies and previous research papers [24], [39], [85], [86], [131], [132], [133], [134], [135], [136].

A. K-12 EDUCATION

K-12 education, refers to the education from kindergarten to 12th grade. This education aims to provide students with the knowledge, skills, and values necessary for personal and social development [137]. K-12 education plays a critical role in preparing students by providing them with a solid foundation in science, technology, engineering, and mathematics (STEM) subjects. This education also provides students with soft skills such as critical thinking, problem-solving, communication, and collaboration [94]. K-12 education can help in creating a talent that can enhance the growth and competitiveness of Industry 5.0.

Several technologies of Industry 5.0 like VR and AR, gamification, and adaptive learning can help to personalize and enrich the learning experience of students. These technologies also improve the efficiency and effectiveness of teaching and assessment [138]. Moreover, Industry 5.0 can provide new contexts and challenges for K-12 education to apply and integrate STEM knowledge and skills, as well as to foster creativity, entrepreneurship, and social responsibility.

B. MEDICAL EDUCATION

Medical education is a course of study intended for people who wish to become physicians to impart the knowledge and skills needed for the prevention and treatment of a disease [139]

Medical education providers and students are facing many challenges that include several aspects like poor work environment, lack of sound infrastructure for medical practice, unethical practices, and weak curricula [140].

Medical education has greatly benefited from the principles and technologies of Industry 5.0. Several enabling technologies of Industry 5.0 like IoT, Big data, Robotics, Cloud computing, BC and AR, and VR play an important role in medical education [90]. The medical educator can create personalized learning methods using AI and ML. These learning paths help students understand the application of medical concepts and procedures. Technologies like VR and AR help medical students to practice surgical procedures, diagnose patients virtually, and to understand complex processes in a risk-free environment. When applied to the traditional training methods the students get the opportunity to learn and make mistakes without any real-world consequences [141].

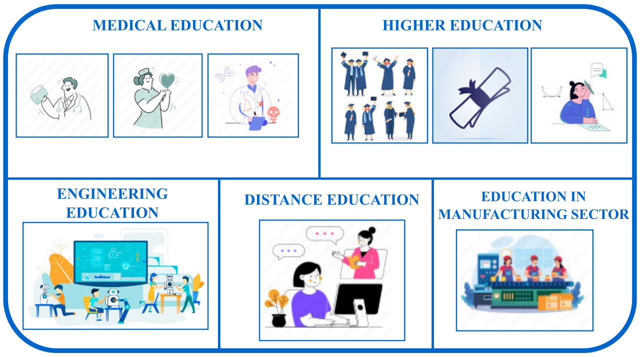

FIGURE 5. Applications of Industry 5.0 in education.

The use of IoT in institutions provides quality remote learning experiences which include virtual dissections, remote participation in certain medical procedures, and interactive lectures. IoT enables smart medical campuses, improving efficiency and security, and providing real-time awareness of various hospital operations [142]. The technologies help students to understand and visualize complex medical scenarios. They also help in automatic administrative tasks in medical education from tracking the student progress to scheduling classes and exams [143]. BC can provide secure and safe records for student assessments, certifications, and accreditation. With the integration of Industry 5.0 technologies in medical education, the student can be prepared for the future where such technologies will be considered vital to healthcare [144]. They can learn about robotic surgery, telemedicine, and how to use these tools effectively. Teleconcilium is one such telemedicine direction that Industry 5.0 is bringing up which enables communication between the attending physician and consulting physicians from other medical institutions or medical students [145]. Figure 5 discusses various applications of Industry 5.0 in education.

C. FURTHER LEARNING

Higher education is the learning process after a student leaves school. Normally universities and colleges are the places where higher education is given in order to achieve graduation or post-graduation. This type of education boosts the career and earning capability of a student [146].

Many challenges are prevailing in the field of higher education like poor teaching quality, curriculum issues, heterogeneity in the education system, and lack of project-based learning [147]

Industry 5.0 is referred to as an era of human-robot collaboration where humans and machines work together in a shared environment. Few technologies of Industry 5.0 like cobots enable better learning experience [148]. In higher education, they can be used in science and engineering labs, for helping students in complex and unsafe environments, for doing dangerous tasks, or for providing hands-on experience on robots and automation [149]. A few technologies of Industry 5.0 also can assess the student's strengths, weaknesses, and learning preferences to create customized learning content. This can make the learning more enjoyable and effective for a student. The technology of Industry 5.0 called VR and AR creates an interesting learning environment. As an example, the archaeology students can explore the ancient ruins without leaving the classroom. Higher education majorly takes place in universities and colleges where the key enabling technology of Industry 5.0 can be used to make informed decisions [150]. They can understand effective learning techniques, to choose valuable courses. This can also enhance student services from personalized career counseling to mental health support [151]. The key enabling technologies of Industry 5.0 also help students in preparing for their careers. Higher education institutions have the opportunity to lead the way in integrating these cutting-edge technologies into their teaching, learning, and administrative processes [152].

The key enabling technology of Industry 5.0, BC helps in storing the marks and credits of students safely. The information relevant to the online meeting in platforms like Zoom, Cisco Webex, and Microsoft Teams and AR/VR-enabled connection status information can be stored on BC ledgers [153].

D. DISTANCE EDUCATION

Distance learning, often known as e-learning or online learning, involves the separation of teachers and students during instruction and makes use of several technologies to facilitate communication between students, teachers, and other [99], [154].

Distance education has some downsides while offering several benefits. Those downsides include disturbances during the online teaching programs, learners may lose track, computer, and internet reliability, and slow internet service [155].

Strong collaboration between humans and machines is one of the most important characteristics of Industry 5.0 which is not just an automated process but also facilitates human-to-human interactions [11]. The technologies of Industry 5.0 address the main criticism of distance learning: its one-size-fits-all approach. Several AI algorithms provide adaptive learning material and resources that make distance learning much more effective and personalized [156]. Technologies like AR and VR provide interesting learning experiences that make students more engaged. VR is used to create virtual labs where students conduct experiments or simulate real-life scenarios for vocational training. This significantly enhances the practical learning experience which is often lacking in traditional distance education. IoT is considered the best interactive tool and provides better connectivity [157]. The BC provides a secure and immutable record of academic credentials, which addresses the issue of certification and verification in distance education. High-speed 6G network and EC can reduce the latency issues which ensure seamless, real-time interactions during online classes [158]. This enhances the quality of distance education which sometimes is much more advanced than classroom learning. Cobots enable physical interactions like labs or arts and crafts activities that were considered very difficult in distance learning environments [159]. These technologies, when combined effectively, have the potential to revolutionize distance education, making it more personalized, interactive, engaging, and efficient.

E. ENGINEERING EDUCATION

Engineering education teaches the knowledge and concepts of the professional practice of engineering. It also covers engineering research and teaching which supports technological and educational innovations [160].

Engineering education has several limitations like lack of diversity, low retention rates, and heavy dependence on international graduate students.

The enabling technologies of Industry 5.0 have the capability to address various limitations of engineering education and transform the learning experience for students. Several technologies of Industry 5.0 like AR, VR and Cobots,offer interesting and hands-on learning experiences [26]. Students can gain practical skills and can understand the engineering concepts which are complex. The simulation environment provided by Industry 5.0 technologies allows students to work on realistic engineering challenges and scenarios. These simulations cover the gap between theory and practise, thereby preparing students for real-world engineering applications [161]. Th technologies of Industry 5.0 can enable the engineering education to incorporate interdisciplinary projects and courses to foster collaboration and encourage innovative problem-solving approaches. The Industry 5.0 technologies like 6G and beyond facilitate global collaboration among these students and educators. Virtual conferencing, online collaboration platforms, and remote learning tools enable seamless international cooperation, providing diverse perspectives in engineering education [162]. Technologies like cobots and DTs in Industry 5.0 can handle repetitive tasks which free up time for students to focus on creative and innovative aspects of engineering. By integrating Industry 5.0 technologies into engineering education, institutions can produce graduates who are better equipped to adapt to the evolving needs of modern industries. Industry 5.0's focus on human-machine collaboration highlights the importance of soft skills such as communication, teamwork, and adaptability [163]. Engineering education can emphasize the development of these essential skills to prepare students for diverse and dynamic work environments.

EC, on the other hand, collects the data at the source and thereby enables better network performance. EC enables teachers and students to a smoother collection of data [164].

F. SHOP FLOOR TRAINING

Shop floor Training is the systematic teaching of the knowledge and processes involved in industrial design and manufacturing [165].

The manufacturing sector faces some downsides while embedding innovative mindsets and entrepreneurs into the educational systems, providing a way to balance the replacement of low-skilled job people with highly skilled people, and training high-level personnel for new high-added-values manufacturing jobs [166].

Shop floor Training in Industry 5.0 focuses on improving quality and productivity through the use of innovative technologies like AI, robotics, and automation. It places a strong emphasis on obtaining more advanced skills, including social skills, creativity, critical thinking, and problem-solving [167]. Industry 5.0 technologies like VR and AR provide interesting, realistic training environments for the manufacturing sector. This allows learners to safely practice complex procedures. 6G networks and EC facilitate real-time, remote instruction, while the IoT provides a realistic understanding of manufacturing workflows. BC enhances the credibility of training completion and certification. The cobots simulate real-world manufacturing tasks for hands-on training [168]. Ultimately, Industry 5.0's human-centric design help in maintaining a balance between technical and soft skills in shop floor training, preparing workers for the evolving demands of the industry. Table 3 refer to the usage of technologies in applications of Industry 5.0.

In summary, the applications of Industry 5.0 in education have the potential to transform the way of teaching and learning. By integrating technologies such as IoT, AI, VR, AR, cobots, and DT, a human-centered, personalized learning environment can be created that meets the needs of both students and teachers. From medical education to engineering to distance learning, Industry 5.0 technologies address the constraints and challenges facing educational institutions, enabling the introduction of innovative teaching methods, distance learning, and intelligent classroom management. By embracing these technological advances, a path can be laid for a more efficient, effective, and accessible education system, preparing tomorrow's workforce for the demands of a rapidly evolving world.

Due to its ability to give students access to a vast array of learning materials, facilitate educators' ability to tailor the curriculum, and give students access to cutting edge teaching instruments, the use of advanced educational technologies are essential to education. A more effective, individualised, and efficient educational system can result from the revolutionary learning that these technologies can bring about in pupils. There were numerous educational applications introduced by Industry 5.0. The implementation of intelligent learning environments and classrooms is one way that Industry 5.0 is being used in education. These classrooms make use of interactive whiteboards, virtual reality, and smart boards to improve student learning. For instance, students can study practical skills like surgery or auto repair through virtual reality simulations.Using AI and machine learning to tailor each student's educational experience is another way Industry 5.0 is being used in education. This can be achieved by utilising adaptive learning software, which modifies the

TABLE 3. Usage of technologies in applications of industry 5.0.

Technologies	Blockchain	EC	AR and VR	IoT	DT	Cobots	Big Data	6G and Beyond	Remarks
Medical Education	H	H	H	M	H	H	M	L	Current technological advances have the potential to deprive medical students of practical and clinical experiences, face-to-face interactions, and communication skills.
Higher Education	H	M	H	M	M	H	M	L	Devices interfere with learning and disturb it. Additionally, it leads to problems with data privacy and educational dishonesty.
Engineering Education	H	M	M	H	M	M	M	L	Education costs are rising along with ineffective teaching strategies.
Shop floor training	M	M	H	H	H	H	M	M	As a concern is that unemployment will increase as a consequence of technology replacing the use of humans in production.
Distance Education	M	M	H	M	L	M	H	L	Students can access online classrooms and learning resources through remote learning. In spite of several technological advancements, students might not experience an actual campus.

H High Utilization M Medium Utilization L Low Utilization

curriculum and degree of difficulty in accordance with the needs and performance of each student. This guarantees that students are getting the greatest education possible while letting them learn at their own speed. Big data analytics is also being used in education to monitor student development and pinpoint areas in which they might require more help. Teachers can utilise this information to modify their lesson plans and teaching strategies so that they better suit the requirements of their students. Predictive analytics is also used to identify kids who are at risk of falling behind or quitting school, giving teachers the opportunity to step in and offer extra assistance. Wearable technology integration, like smartwatches or fitness trackers, can be utilised to monitor students' physical activity levels and promote healthy lifestyle choices. Additionally, the use of AI-based intelligent scheduling systems makes it possible to create customised class schedules for every student according to their interests and academic requirements. Additionally, by analysing student data and spotting patterns and trends, machine learning algorithms can assist educators in customising their pedagogical approaches.

VII. RESEARCH AND INDUSTRY CASE STUDIES

In this review, we conducted a comprehensive case study analysis to provide an insightful overview of initiatives addressing the integration of Industry 5.0 in smart education.

Case Study Analysis Methodology: The search for relevant case studies involved employing key terms such as "case study for Industry 5.0 in smart education," "case study for Industry 5.0 in education," "case study for Industry 5.0 in municipal education," and "case study for Industry 5.0 in medical education." The references reviewed were carefully selected from reputable sources, including book chapters, authenticated web pages, and review papers.

Following the identification of potential case studies, we screened them based on their titles, excluding those that did not align with the scope of the present context. The next step involved a thorough reading of the selected articles to understand their contributions to the field. Subsequently, we structured the case studies by summarizing crucial details, such as the commencement date, location, objectives, and the initiating entity, providing a comprehensive overview of each case study. Following are a few case studies where Industry 5.0 is applied in the education sector.

A. CASE-STUDY-1:INDUSTRY 5.0 FOR INDONESIAN STUDENTS ATTITUDES TOWARDS ENGLISH AS A FOREIGN LANGUAGE (EFL) LEARNING

In the year 2020 in Indonesia, this case study was conducted, and the major goal of this case study was to determine how Indonesian students felt about learning English in relation to their readiness to compete in the period of Industry 5.0.

With the use of a descriptive case study approach, the information gathered from a four-point scale questionnaire given to 216 participants from 12 institutions across Indonesia was evaluated. The results show that, despite their favorable views about learning EFL, Indonesian students may not yet be proficient enough in English to work in Industry 5.0.

In order to ensure that graduates will be able to meet the expectations of Industry 5.0, it is advised that policymakers and all education stakeholders take the required steps to strengthen the students' English abilities [169].

B. CASE-STUDY-2: INDUSTRY 5.0 FOR AN EDUCATIONAL MODEL FOR WORKING ADULTS IN IRELAND

This study was conducted in Ireland in 2022, and the major purpose of this study is to outline how a new pedagogical educational model for working adults in Ireland, was developed to fulfil the demand for upskilling seasoned technical personnel. The software was developed through primary and secondary research to satisfy the changing requirements of Industries 4.0 and 5.0.

The structure of the program is based on social theories sciences and education where terms like 'conceptual frameworks', 'models', and 'constructs' are widely used to define in particular the theoretical summary of the program aimed at technotronics specialists. The program is combined with the research results of the study by Costelloe, Doyle-Kent, and Kopacek (2019) of a large engineering cohort from an Irish bio-medical company.

The newly created curriculum takes on the challenge of expanding and enhancing the existing teaching and learning paradigms in technical education [170].

C. CASE-STUDY-3:INDUSTRY 5.0 FOR MUNICIPAL EDUCATION IN SAMARA OBLAST

The objective of the case study is to assess the municipalities in Samara Oblast's readiness to adopt Industry 5.0 technology.

The authors propose a mathematical model that can be applied to select projects that are best suited for the present condition of Industry 5.0 preparation, identify the major hurdles, and assess the degree to which communities in the Samara Oblast are able to implement Industry 5.0 technologies with a significant rise in municipalities' competitiveness. Innovative measures of municipalities' readiness for Industry 5.0 were developed as a result of the study.

During the course of the study, 12 factors of competitiveness were considered to be a feature of the current level of Regional socio-economic development. Each element has its own significance that determines, its contribution to the final value of competitiveness. Element weights vary by region that reflects the differentiation of the Current state of the development process.

The analysis's innovative indicators, which show how prepared communities are for Industry 5.0, also take into account factors like how simple it is to make products, the effect of society, how quickly new technologies are adopted, and other factors [171].

D. CASE-STUDY-4:INDUSTRY 5.0 FOR SOCIAL SCIENCE STUDENTS

The ability to handle academic strain is referred to as academic resilience. People living in the Industry 5.0 age need persistence in order to deal with the problems that arise in the future. This study evaluated how academically robust social science students were in the face of the Industry 5.0 era. A survey design was employed for this case study. The sample consisted of 116 Social Sciences students who were selected using a proportional stratified random selection methodology. Records on academic success were gathered through a survey. Its validity and reliability were assessed with a value of 0.741 for Kaiser-Meyer-Olkin(KMO) and Bartlett's Test.

Data were descriptively looked at. Students' aptitude, self-assurance, character, devotion, curiosity, and self-control in handling present difficulties served as examples of academic resilience [172].

E. CASE-STUDY-5:INDUSTRY 5.0 AS DRIVING FORCE FOR UNIVERSITIES IN EUROPE

Industry 5.0 is not just a replacement for or a simple chronological continuation of the Industry 4.0 concept. Universities could see things from new angles thanks to digitalization, which has the potential to become one of their key change agents. Universities and societies will both benefit from the digital revolution if the assumptions of Society 5.0 and Industry 5.0 are included in the practices and policies of higher education institutions. Creating new collaborative models and institutions with human-centered innovation will also aid in achieving sustainable goals [173]. The Quintuple Helix Model (QHM), which incorporates several views and establishes sustainability objectives and considerations, may encourage the process of essential reforms. To create innovative approaches and methods for the dissemination of education, research, and technology, QHM offers several proposals for institutions [174].

Through a variety of means, I5.0 encourages universities to adopt an energy-reduction attitude. The most significant development, though, is that colleges are now employing big data analysis to reduce energy use and improve efficiency. The provision of both online and offline education is fundamentally dependent on the economic utility of electricity. Power availability varies, and the cost of electricity is rising. Because it lessens the impact of energy derived from fossil fuels, it benefits the environment but also affects university operating costs. To provide online and offline courses efficiently, colleges must implement a sustainable digital transformation strategy that includes both sophisticated physical infrastructure and software applications. Information processing, information exchange, data storage, web and multimedia services, and data growth management become crucial in the education industry. As a result, increased power usage at universities is anticipated. It is a characteristic of university 5.0.The use of sustainable digital infrastruture (SDT) has radically improved the process of education delivery which encourages optimization of energy, reducing e-waste, promotes circular economy, reuse and recycling. In the scope Education 5.0 based University level frameworks, the circular economy and ecological impact (EI) are intimately related. EI promotes cooperative and practical socioeconomic theories for long-term growth. It is not restricted to economic, social, or environmental concerns; rather, it seeks to meet present-day demands without endangering those of future generations. Virtualization and cloud computing (CC) have significantly decreased university operating workload and power consumption. More specifically, cloud computing drastically lowers the total fixed cost associated with setting up the IT infrastructure, while virtualization has assisted in reducing the number of computers and savers [74].

F. CASE-STUDY-6:INDUSTRY 5.0 FOR THE CREATION OF EDUCATIONAL TESTBED

The changes brought due to the Industrial Era over time have had an effect on employment descriptions, as well as the qualifications of people and how the industry performs. Institutions that support capability must adopt new educational models to qualify and requalify people in view of the rise of Industry 4.0 and the following evolutionary stage known as Industry 5.0. As part of the case study, the preferred reporting items for systematic reviews and meta-analyses method was used as methodology and 47 publications related to this topic were identified. The research findings reveal that eight key features of the educational testbed, university-industry ties, and five major areas make up the concept of the testbed. Digital technologies may be integrated into a virtual environment known as an educational testbed to advance teaching, but in order to inform future research, it is essential to comprehend what an academic testbed includes.

The educational testbed should promote engineering education and the development of skills relevant to the 5.0 workforce [62].

G. CASE-STUDY-7:INDUSTRY 5.0 AND STUDENT SATISFACTION IN EDUCATION

University education has been greatly impacted by the advent of the industrial revolution 5.0. COVID-19 also has impacted the education system greatly which in turn affected student satisfaction in taking education. To satisfy students, universities must enhance the quality of their services and information. In this study [175] considered 100 students of informatics engineering education as their subject of research. A regression test was used for data analysis.

The results showed that the quality of information and service together had a lot of impact on student satisfaction with education. These results suggest that to satisfy college students and enhance competitiveness for Industry 5.0, information quality and service quality must be updated.

H. OVERALL ANALYSIS AND OUTCOMES OF THE CASE STUDIES

Based on the case studies the following conclusion can be derived:

Common Goal:

- All case studies aimed to address the integration of Industry 5.0 principles into various aspects of education, including language learning, workforce upskilling, municipal education systems, student resilience, university practices, and educational testbed development.

Methodological Approach:

- Each case study employed distinct methodological approaches tailored to its specific objectives, including survey designs, mathematical modeling, literature reviews, and theoretical frameworks.

Insights on Industry 5.0 Integration:

- The case studies provided valuable insights into the challenges and opportunities associated with integrating Industry 5.0 principles into education system.
- They highlighted the importance of language proficiency, workforce training, technological readiness, resilience-building, and collaborative innovation in preparing individuals and institutions for Industry 5.0.

Policy Implications:

- The outcomes of the case studies underscored the need for policymakers and education stakeholders to formulate strategies and policies that foster language proficiency, promote innovative pedagogical models, and enhance technological readiness.
- Recommendations were made to strengthen collaboration between academia, industry, and government to align educational practices with the evolving demands of Industry 5.0.

Practical Implications:

- Practical implications included the development of tailored educational curricula, the adoption of innovative teaching methods, the establishment of industry-academia partnerships, and the implementation of resilience-building programs.
- These initiatives aimed to bridge the gap between traditional educational practices and the emerging requirements of Industry 5.0, ensuring that individuals and institutions remain competitive in a rapidly evolving landscape.

Knowledge Gaps and Future Research:

- While the case studies provided valuable insights, they also highlighted knowledge gaps and areas for future research.
- The need for longitudinal studies, interdisciplinary research collaborations, and cross-sectoral partnerships was emphasized to further explore the implications of Industry 5.0 on education and inform evidence-based policy decisions.

Overall Contribution:

- Collectively, the case studies contributed to advancing our understanding of the role of education in the era of Industry 5.0.
- They provided practical recommendations and theoretical frameworks for educators, policymakers, and researchers to navigate the complexities of Industry 5.0 integration and foster a skilled workforce capable of driving future innovation and economic growth.

VIII. LESSONS LEARNED AND DISCUSSION

This section discusses the lessons learned from the current state-of-the-art studies, and based on these lessons synthesizes the future research challenges that need to be addressed to pave the way for an efficient Industry 5.0 and smart education ecosystem.

A. ROLE OF KEY ENABLING TECHNOLOGIES IN INDUSTRY 5.0 IN SMART EDUCATION

From the technologies discussed above by the authors, the following are the lessons learned:

- Integration of several Technologies: The integration of several technologies like Big Data, IoT, BC, EC, AR, VR, DTs, Cobots, and 6G creates a transformative educational ecosystem. There is a need the educational institutions to consider these technologies to create a positive impact [176].
- Data-driven Decision-making: Big data plays a crucial role in decision-making, curriculum development, and personalized learning experiences. However, challenges such as data inconsistency, heterogeneity, and ethical concerns must be addressed [177]. Lessons learned include the importance of effective data governance policies, ethical considerations, and the need for a skilled workforce to manage and analyze big data.
- Real-time Analytics with IoT:
The collection and analysis of real-time data are enabled by IoT, which helps educators understand behavior, learning patterns, and student performance. However, there is a need for attention to address the challenges like data privacy, security, and interoperability [178]. Establishing robust policies, and standards, and investing in infrastructure and cybersecurity are required for the successful implementation of IoT networks.
- Blockchain for Secure Records: BC ensures secure and tamper-proof storage of academic records and certifications. The technology enhances transparency, enables secure sharing of educational content, and simplifies verification processes [179]. However, scalability issues, energy consumption, integration complexities, and the need for standardization pose challenges.
- Edge Computing for Efficiency: EC addresses the challenges associated with managing large volumes of data generated by IoT devices in educational settings. While it offers continuous connectivity and real-time processing, challenges include infrastructure costs, data security, and interoperability [180].
- Immersive Experiences with AR and VR: AR and VR provide immersive learning experiences, making education more engaging and effective. However, challenges such as high costs, accessibility, infrastructure requirements, and the need for teacher training need to be considered for successful implementation [181].
- Digital Twins for Virtual Experiments: DTs enable virtual replicas of real-world equipment, enhancing hands-on learning in a safe and cost-effective virtual environment. Challenges include the need for accurate and up-to-date data, computational resources, and privacy and security considerations [182].
- Collaboration with Cobots: Collaborative robots enhance hands-on learning, foster collaboration, and reduce administrative burdens. Challenges include ensuring safe human-robot interaction, infrastructure modifications, and ethical considerations related to privacy and data security [183].
- Next-generation Connectivity with 6G: 6G offers ultra-fast and reliable connectivity, supporting technologies like AR and VR. However, challenges such as infrastructure costs, specialized knowledge requirements, privacy and security concerns, and ensuring equal access across socioeconomic backgrounds need to be addressed [184].
- Strategic Planning and Policy Development: The successful implementation of these technologies requires strategic planning, robust policies, and standards. Education institutions need to address challenges systematically, invest in training for educators, and ensure privacy and security considerations are prioritized [185].

B. APPLICATIONS OF INDUSTRY 5.0 AND ITS KEY ENABLING TECHNOLOGIES IN EDUCATION

Industry 5.0 technologies, including IoT, Big Data, Robotics, AR/VR, cobots, and 6G, are transforming different aspects of education. They enhance medical education through personalized learning methods and virtual surgical procedures. They address challenges in higher education and revolutionize distance education by offering adaptive learning and engaging experiences. These technologies also transform engineering education by providing hands-on learning experiences and fostering interdisciplinary collaboration. In manufacturing, they improve shop floor training through realistic training environments and remote instruction. Industry 5.0 emphasizes human-centric design and the development of soft skills across various educational applications. It enables global collaboration in education and encourages a balance between technical skills and soft skills. It also enhances the effectiveness of learning by enabling personalized learning experiences. However, careful consideration is needed for challenges such as infrastructure costs and privacy concerns before the widespread adoption of these technologies.

IX. CHALLENGES, OPEN ISSUES, AND FUTURE DIRECTIONS

Industry 5.0, bearing many technical potentials also presents several challenges in the education sector. Potential challenges and open issues include:

A. CHALLENGES

- **Integration of Industry 5.0 Concepts:** The integration of Industry 5.0 concepts into the smart education environment involves incorporating principles like human-robot collaboration and cyber-physical systems to enhance learning experiences. These principles incorporation is quite complex and challenging. Human-robot collaboration in education requires a balance between technological advancements and pedagogical goals [186]. Implementing Cyber-Physical Systems needs a suitable technological infrastructure that ensures interoperability among devices and systems.

Solution:

- Interdisciplinary teams comprising educators, technologists, and industry experts to design and implement integration strategies are to be established.
- Pilot projects and prototypes are to be developed to test human-robot collaboration and cyber-physical systems in educational settings.
- Professional development programs need to be offered for educators to enhance their understanding of Industry 5.0 concepts and technologies.

- **Technological Infrastructure:** Establishing an advanced technological infrastructure is one of the fundamental challenges [78]. This challenge has critical components like ensuring robust connectivity for real-time communication and collaborative interactions, handling large data volumes through ample bandwidth, achieving seamless integration of diverse technologies with interoperability, adapting the infrastructure to evolving needs through scalability, safeguarding sensitive data with robust cybersecurity measures, and fostering adaptability to emerging technologies.
  Solution:
  - Invest in upgrading network connectivity, bandwidth, and cybersecurity measures to support real-time communication and data handling.
  - Protocols should be made to ensure interoperability among diverse technologies used in the smart education environment.
  - collaboration between educational institutions and technology providers need to be improved to adapt infrastructure to evolving needs.
- **Skill Development:** Another pivotal challenge is recognizing and bridging the skills gap among both educators and students to harness the full potential of Industry 5.0 technologies in education. This includes comprehensive training programs for educators that help them in grasping the principles of Industry 5.0 [187]. These programs focus on enhancing technological proficiency, incorporating tools such as collaborative platforms, AR, and VR into pedagogical practices. For students, it is challenging to develop digital literacy, communication, and critical thinking skills essential for engaging in projects that involve human-technology collaboration [188].
  Solution:
  - Provide comprehensive training programs for educators to enhance their technological proficiency and integrate tools like collaborative platforms, AR, and VR into pedagogical practices.
  - Incorporate digital literacy, communication, and critical thinking skills development into the curriculum to prepare students for projects involving human-technology collaboration.
  - Establish partnerships with industry to offer internship programs and real-world projects for students to gain hands-on experience.
- **Privacy Concerns:** In the context of Industry 5.0 integration in education, prioritizing security, privacy and ethical considerations becomes paramount. The inclusion of several technologies of Industry 5.0 raises societal concerns. There is a lot of exchange of data between different institutions, between the educators and students in Industry 5.0. The data can be sensitive and needs to be made private from malicious users on the Internet [189]. The implementation of several technologies of Industry 5.0 in education needs to stick to specific societal and ethical implications to avoid the negative societal impact. Data privacy must ensure that the user data is safeguarded [47].
  Solution:
  - Implement robust data privacy and security measures to safeguard sensitive information exchanged between educators and students.
  - Develop clear policies and guidelines for data usage and sharing to address ethical considerations.
  - Provide training and awareness programs for educators and students on data privacy best practices.
- **Cost and Resource Allocation:** A skilled workforce is crucial for imparting education in Industry 5.0 and is expected to deliver high-value knowledge. The process of developing a skilled workforce involves addressing various concerns related to management, educators, and educational institutions [190].One major challenge in the realm of skill development is the shortage of qualified trainers, coupled with financial constraints that hinder the ability to provide proper training to educators. As Industry 5.0 becomes fully adopted, the demand for a skilled workforce will increase, necessitating adequate training for both students and prospective educators. Additionally, with the continuous evolution of new technologies, ongoing training programs will be essential to keep up with the latest advancements [20]. Another issue is that some educational institutions may lack the necessary infrastructure to accommodate the new technology. This infrastructure gap poses a challenge to the seamless integration of Industry 5.0 in the education sector. Addressing these challenges in cost and resource allocation is imperative to ensure the successful implementation of Industry 5.0 in education.
  Solution:
  - Allocate resources for training programs to address the shortage of qualified trainers and educators.

- Seek funding opportunities from government grants, private partnerships, and educational foundations to support the adoption of Industry 5.0 technologies.
- Prioritize investments in infrastructure upgrades to accommodate new technologies and ensure seamless integration.

- **Pedagogical Adaptations:** Pedagogical adaptations is a critical challenge when pertaining to Industry 5.0. In order to align with changing needs of Industry 5.0, evolution of educational pedagogies involves adapting teaching methods and strategies [191]. The evolution includes interactive and dynamic teaching techniques, integrating real-world case studies and industry-related projects into the curriculum, leveraging technology for virtual labs and simulations, fostering interdisciplinary approaches, inviting industry experts for guest lectures, and utilizing gamification for interactive learning experiences. The educational strategies are to be aligned with the principles and demands of Industry 5.0 and prepare students for the ever-changing industrial landscape and improve their overall learning experience [192].
  Solution:
  - Encourage the adoption of interactive teaching techniques, real-world case studies, and industry-related projects in the curriculum.
  - Provide professional development opportunities for educators to learn about innovative pedagogical strategies aligned with Industry 5.0 principles.
  - Foster collaboration with industry experts to offer guest lectures and mentorship programs for students.
- **Accessibility:** Its is challenging to make Industry 5.0 technologies accessible to every student, irrespective of their diverse learning needs. It is very important that the Industry 5.0 technologies can work with the assistive tools like screen readers and voice recognition. There are also several challenges that are to be traced, like unequal internet access and different types of devices [94].
  Solution:
  - Develop assistive technologies compatible with Industry 5.0 tools to ensure accessibility for students with diverse learning needs.
  - Address disparities in internet access and device availability by providing subsidies or loan programs for students from underserved communities.
  - Design educational materials and platforms with universal design principles to accommodate different types of devices and learning preferences.
- **Curricular Adaptation:** The curriculum adaption is one of the major challenges in the context of Industry 5.0 and education. It is very complex to update and align the educational curriculum with the ever-changing requirements of the transformative industrial paradigm. It is very tough for the educators to integrate new concepts, advanced technologies and required skills associated with Industry 5.0 into the already existing courses. There is a need to balance between the existing curriculum and the new curriculum without diluting the core objectives [84]. Figure 6 illustrates the challenges and future directions.
  Solution:
  - Review and update the curriculum regularly to incorporate new concepts, technologies, and skills associated with Industry 5.0.
  - Offer training and support for educators to redesign courses and lesson plans to align with the changing requirements of the industrial paradigm.
  - Collaborate with industry partners to identify emerging trends and skill requirements to inform curricular adaptations.
- **Assessment and Evaluation:** The integration of Industry 5.0 and education faces a unique challenge in developing assessment methods that can efficiently evaluate the outcomes of innovative teaching methods aligned with Industry 5.0 principles [187].Traditional assessment methods need to be adapted to capture not only theoretical knowledge but also measure the practical applications of skills related to the rapidly evolving industrial paradigm1. The transition from regular assessment approaches to novel assessment strategies is a challenging task that requires exploration.
  Solution:
  - Develop innovative assessment methods that measure both theoretical knowledge and practical applications of skills related to Industry 5.0.
  - Implement project-based assessments, simulations, and real-world challenges to evaluate student learning outcomes.
  - Provide training for educators on designing and implementing novel assessment strategies aligned with Industry 5.0 principles.

Although the implementation of Industry 5.0 in education has wide range of benefits, but there are associated challenges as well. Firstly, data usage and privacy can act as a concern wherein collection of irrelevant data for the purpose of commercial purposes can be questioned. The improper storage of the collected data from students can also lead to breaches making the system vulnerable to unauthorized access. The third party vendors who provide technological support often get access to academic data. If socioeconomic, geographic, or other constraints prevent some student populations from accessing or using smart educational resources, there is a chance that disparities may be created or maintained. Secondly, there are issues pertaining to long-term implications of digital footprints. Risks arise from long-term retention, particularly if the information ages or becomes inaccurate about a student's future potential.Therefore, after a specific amount of time or after completing their study, students should have the right to request that their data be deleted. Giving people control over their

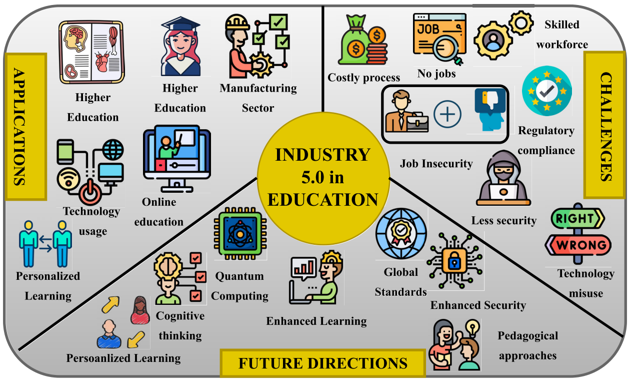

FIGURE 6. Challenge and Future Directions.

digital records is morally right. Thirdly, in terms of the use of AI, ML and related technologies, the decision making process often tend to be black-boxed leading to Institutions not being accountable for the decisions made by the automated systems. Furthermore, because automated systems frequently display biases, care must be taken to ensure that they accommodate a diverse student body and do not reinforce socioeconomic or cultural prejudices. The over-reliance on automation could challenge the overall development of students being ignored in favour of quantitative measurements. In addition to academic improvement, education should foster moral, social, and emotional development [193].

B. FUTURE DIRECTIONS

Shifting learning into Industry 5.0 is still in its infancy. A survey of the existing literature on Industry 5.0 and education has identified a number of promising areas for further study. The ultimate objective is to build a more all-encompassing and human-centered approach to learning and skill development that uses technology to augment human talents rather than replace them [78]. The research topics and the research issues that go along with them that can be investigated in future research. Several research questions arise in pedagogical approaches, technology adoption, technology integration and learning performance, social and emotional development, sustainability, partnerships and collaborations, and personalized learning [86], [194].

- Interoperability: In the context of Industry 5.0 in Smart Education, interoperability is considered as the ability of multiple systems, technologies, and devices to work together and exchange information seamlessly. In smart educational environments several platforms, tools, and applications are used for data analysis, learning, and assessment. In this view, interoperability is crucial to ensure that these different platforms can communicate and integrate effectively, enabling an efficient educational experience [195].
- Explainability: Explainability is the ability to understand and interpret the decisions or the results that are generated by any of the learning algorithms. As AI-driven technologies are widely used in smart education, it is needed to assure that these algorithms can provide transparent and interpretable explanations for their results. In educational settings, where students, teachers, and administrators are needed to justify the reason behind the AI-generated feedback, recommendations, and assessments [196].
- Privacy: Privacy is a critical issue in any technology-based industry, and smart education is no exception. With the integration of Industry 5.0 technologies and the use of massive amounts of data, maintaining the privacy of students, teachers and stakeholders is paramount. As a future direction, several privacy-preserving techniques and guidelines can be explored to protect sensitive information while using advanced technologies in smart education [197].
- Data Heterogeneity: In the view of smart education and Industry 5.0, data heterogeneity refers to the variability ad diversity of data sources, formats, ad structures. Educational data can be from different sources and like LMS, sensors, social media platforms, and more. As a future direction, more techniques should be adopted to handle, process, and make use of the diverse data to conclude meaningful experiences and thereby improve the learning experience [198].
- Personalization: Personalization in the context of Industry 5.0 in smart education refers to the tailored learning experiences that can fulfill the needs of varied-natured students [199]. As Industry 5.0 offers more opportunities for data gathering and analysis, there is an increased need to create personalized learning pathways and educational content. As a future direction, effective personalized learning techniques should be implemented [200].
- Teacher Training and Professional Development: As technology becomes more prevalent in educational settings, teachers need to be adequately trained and prepared to integrate these tools effectively into their teaching practices. As a part of future direction, the importance of ongoing teacher training and professional development programs are needed to equip educators with the necessary skills and knowledge to leverage Industry 5.0 technologies for improved student outcomes [201].
- Forward-Looking Insights: While discussing the challenges of Industry 5.0 in education, offering forward-looking insights and recommendations for future research is crucial. By focusing on personalized learning, immersive technologies, ethical considerations, and collaborative efforts, we can guide scholarly endeavors in this field and facilitate the successful adoption of Industry 5.0 technologies in education [202].

X. CONCLUSION

This survey aims to understand the potential role of recent technological developments in providing inclusive education for students within the context of Industry 5.0 in smart education. Throughout this process, we analyze the learning and support needs that arise as a result of a student's engagement with Industry 5.0. This paradigm emphasizes the synergy between humans and advanced technologies, aiming to improve workplace processes while focusing on personal needs, resilience, and sustainability. The integration of Industry 5.0 into Education 4.0 is pivotal, enhancing the learning experience through advanced technologies and personalized education. Key enabling technologies like big data, IoT, and blockchain play a crucial role in the evolution of smart education, offering innovative ways to engage and educate. Research and industry case studies demonstrate practical applications and the positive impact of Industry 5.0 on various educational settings, from K-12 to professional training. Addressing challenges and exploring open issues will pave the way for future advancements, ensuring that education remains relevant and effective in the rapidly evolving technological landscape. The study traces the evolution from Education 1.0 to Education 4.0, setting the stage for integrating Industry 5.0 to enhance the teaching-learning process. It describes the application of Industry 5.0 across various educational sectors, including medical, distance, engineering education, and shop floor training.

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