Implementation of Industry 4.0 Technologies in Technical and Vocational Education in Maharashtra

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***Abstract*— Lot of transformation in industries in all areas are due to Industry 4.0 technologies including Internet of things, (IoT), Artificial Intelligence (AI), Robotics, data analytics, Automation etc. which requires skill development among employees. The industrial training institutes and vocational courses must integrate these technologies in their courses for using Industry 4.0. This research aims to apply Industry 4.0 in technical and vocational education with enhanced quality and in alignment with the demands of modern industries. The main focus being on upgrading infrastructure, making curricula modern, training to faculties, and promoting industry collaboration to develop a skilled workforce expert in Industry 4.0 technologies. Key components include the establishment of smart labs equipped with IoT-enabled devices, Augmented Reality and Virtual Reality tools, and robotics systems; the inclusion of Industry 4.0 elements into the curriculum; and the imparting of hands-on training through industry partnerships and exposure to live projects. There are various phases of implementation like planning and pilot implementation, state-wide rollout, monitoring, evaluation and continuous improvement. Expected outcomes include improved employability of vocational graduates, enhanced industry collaboration, and remarkable reduction in the skill gap. By equipping students with Industry 4.0 skill sets and knowledge to create a future-ready manpower capable of driving innovation and getting economic growth. The scalable model developed through this initiative will ensure widespread adoption of Industry 4.0 in vocational education systems. This research represents a significant step towards modernizing vocational education, fostering industry-academia collaboration, and preparing the workforce for the challenges and opportunities that will be due to the Fourth Industrial Revolution.**

Keywords—Industrial Training Institute, Higher vocational education, quality monitoring and evaluation, training system.

I. Introduction

Industry 4.0 means the fourth industrial revolution. It integrates advanced technologies into manufacturing and industrial services like the Artificial Intelligence (AI), Internet of Things (IoT), robotics, big data, cyber-physical systems (CPS) and cloud computing etc[1]. The AI systems deliver learning content through personalized lessons with quizzes that include simulated practice scenarios. The Internet of Things (IoT) connects devices and machineries, which enable real-time data collection and seamless communication to optimize production operations. Robotics enables automation of repetitive, dangerous and labour-intensive tasks reducing production cost and production time. Big data refers to massive volumes of structured and unstructured data generated by sensors, machines, devices and human interaction across production cycle in industry. Big data helps in predictive maintenance, demand forecasting, supply chain automation. Cloud computing provides the infrastructure for storing, processing, and analyzing vast amounts of industrial data enabling real time data sharing, remote monitoring and seamless integration of IoT and robotics. CPS integrate physical processes and computer-based algorithms, letting smart machines to monitor and control operations, that leads to more intelligent and automated manufacturing processes/operations [4].

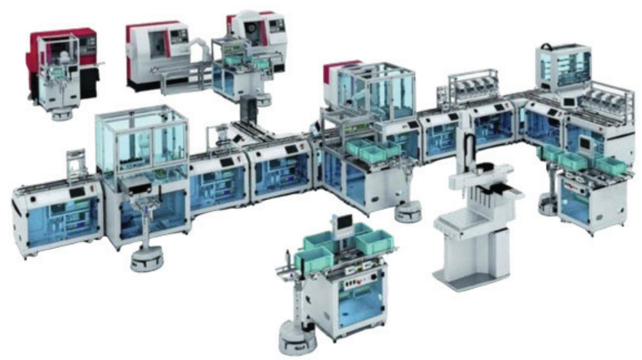

Fig. 1. Exemplary Learning Factory at the technical vocational school in Offenburg [3]

By Integrating Industry 4.0 into Industrial Training Institutes can equip students with the skill sets needed for high-paying jobs in advanced manufacturing, automation, and data analytics. This will much improve their employability and also address the skill gap faced by industries.

Vocational training programs can significantly benefit by incorporating practical, hands-on experience on areas like robotic systems and automation tools, which are very widely used in industries such as manufacturing, logistics, and automotive. By training on these technologies, students will gain essential skills in operating, troubleshooting, and maintaining automated systems, preparing them for real-world industrial challenges. Techniques such as robotic simulators and virtual environments allow students to practice tasks like assembly line operations, equipment maintenance, and problem-solving in a risk-free, cost-effective manner, thus eliminating the need for large-scale physical setups and investment for the same. In addition, exposure to collaborative robots (COBOTS), which work alongside human workers to enhance productivity that helps students develop expertise in human-robot collaboration [39]. This comprehensive approach confirms that students are well-resourced with the technical and practical skills essential to stand in a progressively automated and technology-driven modern workforce.

Students can engage with cutting-edge industrial applications through the integration of IoT (Internet of Things) into vocational training. With the help of IoT devices, students can learn about real-time data collection. By monitoring machinery and production processes, institutes can gain insights into how data is utilized and how to optimize operations. They can investigate predictive maintenance techniques, understand how IoT devices detect faults and predict equipment maintenance needs- a critical skill in industries like manufacturing and energy. Furthermore, IoT-based training kits allows students to gain hands-on experience with smart sensors that monitor variables such as temperature, pressure, humidity, and motion. This educates them how to manage and improve the efficiency of smart systems. This hands-on experience with IoT technologies excels students with the knowledge and skills needed to excel in modern, data-driven industrial environments.

II. Role of Industry 4.0 in Technical and Vocational Education:

Due to rapid advancement in Industry 4.0, industrial scenario has changed drastically, which requires corresponding transformation in Technical and Vocational Education (TVE). Skill requirements across various sectors are changed due to technologies like AI, IoT, robotics, and CPS. TVE institutions must update their courses and training methods as industries adopt these technologies, to ensure graduates remain relevant and employable. Digitization in TVE plays a crucial role to meet these evolving demands. Digitization means the integration of digital tools and platforms into instructive practices, enabling more interactive, efficient, and adaptive learning environments. Industrial and vocational Training Institutes have yet to fully incorporate digital tools in their learning processes, which are online learning platforms, simulators, and virtual labs, these are essential for enhancing the training experience [11]. This lack of modern digital learning methods makes students ill-prepared with respect to the demands of Industry 4.0. It is essential to integrate these tools in Industrial Training Institute’s curricula. It will ensure students are equipped with the practical knowledge and competencies needed to succeed in a technology-driven environment that is being developed.Furthermore, aligning Industry 4.0 with TVE requires collaboration between industry stakeholders, educational institutions and policymakers. By co-developing training programs and updating competency frameworks, these establishments ensure that the employee is equipped with the theoretical knowledge and practical skills necessary for future-oriented careers.The successful integration of Industry 4.0 technologies and digitization into TVE is essential for preparing a skilled, compliant, and future-ready employee. Sustained efforts in course reform, mentor training, and infrastructure investment will be vital to achieve this transformation.

A structured monitoring and evaluation framework enables the tracking of progress and facilitates continuous program improvement through stakeholder feedback. Sustainability is emphasized by integrating Industry 4.0 training into routine operations, allowing for ongoing adaptation to technological advancements [30]. Certification and recognition initiatives provide students and faculty with industry-validated credentials, enhancing career advancement opportunities. Moreover, the initiative promotes innovation and entrepreneurship by encouraging students to develop solutions using Industry 4.0 technologies—paving the way for start-ups and economic growth. The program also ensures inclusive growth by providing equitable access to training for rural and underserved communities. Ultimately, this initiative enhances global competitiveness by equipping students with internationally relevant skills, contributing to economic development and a future-ready workforce.

A. Present State of Industrial and Vocational Training Institutes:

Wide range of skill-based training programs, including courses in electrical, mechanical, and computer programming are offered by Industrial and Vocational Training Institutes. Gaikwad et.al.[7] investigated that still many Industrial and Vocational Training Institutes follow a curriculum primarily designed for conventional industries and have been not updated to integrate Industry 4.0 advancements such as automation, robotics, AI, and IoT. Therefore, the training remains heavily focused on manual skills, which may not fully align with the evolving demands of the digital economy, putting limits on students' readiness for modern, technology-driven industries. The common observation regarding training is many Industrial and Vocational Training Institutes continue to use old equipment’s and infrastructure, which may hamper the quality of training considerably. Technology used for training is lacking the modern tools, machinery, and software necessary for students to gain practical experience in emerging fields like robotics, AI and IoT. This is a gap in technological integration. It hinders students' ability to acquire the skills required according to the modern industrial requirements [29].

A major challenge faced by Industrial and Vocational Training Institutes is the poor availability of qualified instructors well proficient in advanced Industry 4.0 technologies. Though many trainers have expertise in traditional industries, they mostly lack the necessary knowledge in these emerging fields such as AI, data analytics, and automation etc. This gap in expertise put limits to the ability of Industrial Training Institutes to effectively develop students with the skills necessary for the modern, technology-driven manpower [31].

Another challenge is limited collaboration with the industry, generating a mismatch between the skills taught in their training programs and the actual demands in the market. Industry 4.0 accelerates technological advancements, so it has become increasingly important for Industrial Training Institutes to establish stronger relations with industries. Such collaborations may enable Industrial Training Institutes to keep their curricula in alignment with the latest technological developments and provide students with hands-on experience by relevant tools and technologies, hence bridging the gap between education and industry requirements to much extent.

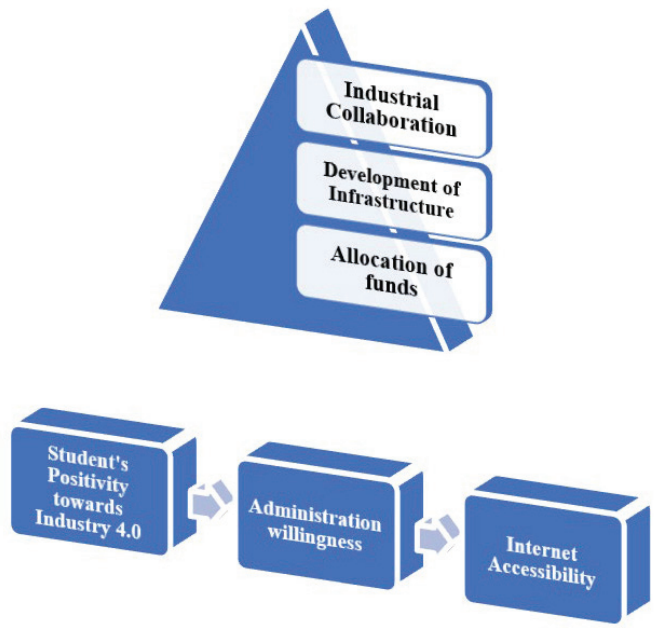

Fig. 2. Basic framework of business model for Industry 4.0[9]

Many Industrial Training Institutes still follow outdated curricula and fail to adequately address these emerging areas. For bridging this gap, there is an urgent need for a significant change in training programs, having focus toward digital literacy, data analysis, robotics, and AI, but still maintaining foundational traditional skill sets as it is. This will ensure that students are equipped with the knowledge and expertise required to cope up the rapidly evolving industrial environment.

Faller et.al. explored the integration of Industry 4.0 technologies in industrial training institutes do skill development by equipping students with expertise in these technologies like IoT, AI, robotics, automation, big data and cybersecurity, ensuring that they are prepared for modern industries. Modernization in curriculum have aim to align training programs with modern industry standards. [4] This incorporates both theoretical and practical applications. Infrastructure enhancement may involve upgrading institutes with smart labs, IoT-enabled devices, robotics kits, and simulation software to provide hands-on training. In faculty capacity building, educators receive specialized training through workshops and certifications which enables them to deliver high quality instructions. Kaicker et al. explored that Industry-academic collaboration will allow students to attend internships and live projects which will enhance their real-world exposure and helps to improve employability [28]. Efforts taken to enhance employability will focus on skill alignment of students, which consequently results in improved job opportunities and higher placement rates. The aim of awareness and outreach initiatives is to educate stakeholders on the significance of Industry 4.0, fostering increased engagement. Scalability and replicability ensure the adoptability of the working model across various states modernizing training institutes.

Balaji et.al. investigated that Automation and robotics have made machines increasingly autonomous, reduced the need for human intervention in repetitive tasks [3]. Due to the availability of vast amounts of data, big data and analytics empower companies to make faster, data-driven decisions and enhance operational efficiency, to great extent. Artificial intelligence (AI) and machine learning further improve the process of decision-making by helping systems to learn from past data, facilitating smarter manufacturing as well as predictive maintenance for future. In addition, additive manufacturing, such as 3D printing, makes revolution in product design, prototyping, and production by enabling the creation of complex parts with more efficiency.

Augmented Reality (AR) and Virtual Reality (VR) technologies are revolutionizing vocational training. By offering immersive learning experiences that bridge the gap between theory and practice. Through VR, students can engage in realistic simulations [32]. They may be welding, electrical repairs, or assembly tasks, within a risk-free virtual environment, providing hands-on experience. This eliminates the need for costly materials or equipment. Additionally, VR is particularly effective for safety training. As it can replicate hazardous scenarios, such as working with high-voltage systems or heavy machinery, enables students to practice safety protocols in a controlled setting. On the other hand, AR enhances learning by enabling remote assistance, where students can receive real-time guidance and troubleshooting from instructors or experts while performing complex tasks, regardless of their physical location. Together, AR and VR technologies empower students with practical skills, safety awareness, and remote collaboration capabilities, it is preparing them for the demands of modern industries.

The educational field of vocational training undergoes transformation through the implementation of Artificial Intelligence (AI). Smart learning platforms which adjust their content to student individual learning speeds and preferences represent a key method for educational improvement. AI creates individualized training opportunities which produce superior educational outcomes [33]. The teaching tools employ individual achievement methods that help students understand concepts completely. The usage of AI tools provides better assessment capabilities for skills. Highly accurate assessments become possible when instructors use these tools. Detailed reports on areas for improvement, and insights into performance trends over time are generated. Beyond education, students also learn how AI automates repetitive tasks in industries. It may be as customer service, manufacturing, and logistics. This enables workers to focus on more complex and value-added activities. Thakur et al. explored that by integrating AI into training programs, students learn both technical expertise and an insight of how AI is reshaping the modern workforce.3D printing can also be used in vocational training. It can be for repair work, allowing students to reproduce faulty parts. They can learn repair techniques using the printed replacements [8].

B. Global Best Practices

Globally if we observe, Germany's dual education system has successfully integrated Industry 4.0 into vocational training. It is by combining classroom learning with hands-on experience in smart factories. [26] Germany is also implementing learning 4.0 smart factories. This is part of curricula [14]. At the same time China has established 'smart manufacturing' training centers in vocational schools. They are to prepare students for Industry 4.0 jobs. [2] Otara et.al. explored international educational responses to the Industry 4.0 underlining transformative impact of technology. The education system of Singapore, Finland and Rwanda has integrated Industry 4.0[12]. Austria and Switzerland have integrated Industry 4.0 into their education system [6]. In Malaysia,TVE experts have developed consensus-based models for integrating Industry 4.0 content, emphasizing curriculum development, assessment, and industry collaboration.In Indonesia, revitalization of vocational education is in progress focusing on quality improvement, expanding access, and leveraging technology to develop relevant competencies.In Nepal,studies highlight the need for government intervention and strategic actions to improve industrial readiness and support TVE institutions.

III. Implementation plan:

Vocational education must develop key competencies like critical thinking and problem-solving skills, communication and collaboration abilities, creativity and innovation capabilities, Information Communication Technology literacy and contextual learning skills in the era of Industry 4.0. However, vocational education also faces several challenges in this era like issues related to information technology security, the reliability and stability of production machinery, a shortage of workers with adequate skills, resistance to change among stakeholders, and significant job losses due to automation. [9]

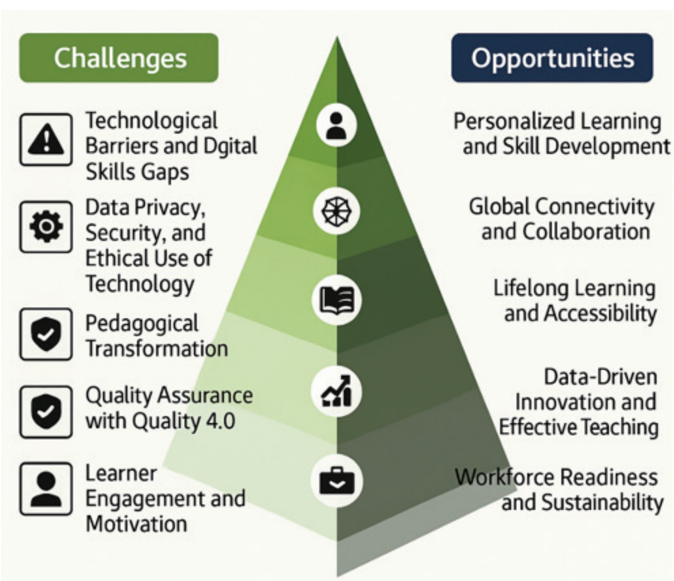

Fig. 3. Industry 4.0: Key Challenges and Opportunities

The implementation of Industry 4.0 in Industrial Training Institutes faces several challenges including the high cost of advanced equipment, the lack of trained instructors, and the need for continuous curriculum updates to keep pace with technological advancements. There are two central questions out of which one is what are the key technologies required for implementing Industry 4.0 in Industrial Training Institutes and second is, how can these technologies be effectively integrated into the existing curriculum. To answer these questions, the research objectives include developing a scalable and adaptable model for Industry 4.0 implementation in it. That will be ensuring that vocational training programs align with the demands of modern industries and equip students with the necessary skills to stand in a technology-driven workforce.

A. Objective of Implementation:

The primary objective of this initiative is to integrate Industry 4.0 technologies such as IoT, AI, robotics, and automation into Industrial Training Institutes which will enhance the quality of vocational education and align it with the evolving demands of the industry. To achieve this, several secondary objectives have been outlined such as upgrading infrastructure to support Industry 4.0 training, modernizing the curriculum to incorporate Industry 4.0 topics, training faculty in these advanced technologies and teaching methodologies, fostering industry collaboration to offer students with practical exposure and internship opportunities [34]. This will finally improve student employability and willingness for Industry 4.0 jobs. To ensure structured and impactful integration of these technologies into vocational training programs we have examined five specific trades where Industry 4.0 can be systematically implemented.

To align Industrial Training Institutes with the demands of Industry 4.0, upgrading infrastructure is paramount. This contains the implementation of smart electrical systems equipped with sensors and actuators, enabling real-time monitoring and control. The integration of smart meters, smart grids, and smart labs will create ultramodern learning environment that mirrors contemporary industrial setups. Additionally, IoT-enabled electrical devices such as motors, geysers, fans, air conditioners, and inverters will provide students valuable hands-on experience in managing and troubleshooting connected systems. The adoption of AR/VR technologies will transform the learning by offering immersive, interactive simulations for complex tasks. Finally, the incorporation of cyber-physical systems will channelize the gap between physical operations and digital control preparing students for the interconnected and automated future of industries. These upgrades will assure that industrial training institutes are equipped to deliver cutting-edge vocational training aligned with Industry 4.0 standards.

Yadav S. explored Industry 4.0 technologies integrated into electric training at industrial institutes help students acquire updated skills needed for current industrial requirements. Students who use IoT-enabled devices and sensors will receive training specifically for installing and maintaining and troubleshooting smart electrical systems. Students will develop competence in operating interconnected systems through this training. Trained professionals will acquire abilities necessary to sustain automated electrical systems installed in manufacturing facilities through robotic automation of conveyor operations. [34]

Students will get expert in Sensor technology and data analysis tools enabling monitoring of equipment, detect potential issues early, predict and prevent electrical system failure. The training incorporates local monitoring through IoT sensors to check critical equipment status including motors and transformers and other electrical systems. Stimoniaris et al. investigate that the educational program includes advanced instruction on IoT-controlled HVAC systems and daylight-activated smart lighting systems to make students proficient in both energy management operations and operational effectiveness [35]. Students who learn these comprehensive abilities will succeed in the fast-moving electrical and automation industries.

Higher education institutions(HEI) must invest in faculty training because this ensures instructors develop competence in Industry 4.0 technologies besides modern teaching strategies. Educational institutions need to provide training that helps instructors master automation and AI and IoT and data analytics to effectively explain these new technologies to students. Such workshops on Industry 4.0 enable educators to stay updated with modern advancements through specialized training programs. Their training quality will improve to match industry specifications because of this initiative. [36]

Infrastructure upgradation in industrial training institutes should focus on integrating cutting-edge Industry 4.0 technologies to enhance hands-on training. This includes integration of autonomous driving systems with advanced sensors, cameras, and AI algorithms, and training on electric and hybrid vehicles, covering batteries, motors, and power electronics. IoT sensors and data analytics can be utilized to predict and prevent vehicle failures, enhancing maintenance efficiency. Augmented Reality (AR) can be used for diagnostics and repair, while 3D printing can provide the rapid production of spare parts. Training workshops should be equipped with IoT-enabled tools and smart diagnostic equipment which will deliver real-time insights. Additionally, implementation of secure communication protocols is necessary to confirm the cybersecurity of vehicle systems. Singh, M. emphasized on the incorporation of collaborative robots (COBOTS) and Advanced Driver-Assistance Systems (ADAS) will further revolutionise the training infrastructure, concocting students for the developing demands of the automotive and manufacturing industries [37].

Kotsifakos et al. suggested that the curriculum requires implementation of teaching methods which focuses on developing student skills for diagnosing and maintaining vehicles equipped with IoT communication and data sharing capabilities [38]. Proposed training must teach students both high-voltage system and charging infrastructure repair techniques and the application of IoT sensors and data analytics for vehicle failure prediction. Students should learn how to interpret information gathered from vehicle systems that cover engines and transmissions and brakes for detecting possible problems. Augmented Reality (AR) tools integrated through headsets or tablets enable students to view step-by-step repair instructions directly superimposed near the vehicle components which improves both their efficiency and accuracy during the repair process. The curriculum should include training for 3D printing to make custom and obsolete spare parts while also teaching advanced diagnostic tools which operate through Bluetooth or Wi-Fi connections. Such updates in the curriculum will prepare students to handle contemporary automotive technologies along with Industry 4.0 progress.

Organizations should invest in faculty capacity building to ensure their instructors understand both Industry 4.0 technologies and modern teaching approaches. The training programs must aim to develop teachers' knowledge in automation and AI as well as IoT and data analytics and modern manufacturing techniques. The institution should organize specialized workshops that prepare faculty members about current industry trends with modern analytical tools and best practices details. These educational programs will boost teaching quality which helps trainers deliver technical training efficiently to students about emerging technologies thus creating a connection between standard education and modern industry requirements.

The welding training infrastructure needs IoT-enabled technologies to boost both operational safeties along with improved precision and efficiency levels. Welding curriculum implementation should deliver education about advanced Industry 4.0 skills for managing and operating IoT-ready welding equipment to students. Trainees should first practice welding simulations based on AR technology before handling real welding operations for MIG (Metal Inert Gas), TIG (Tungsten Inert Gas) and arc welding methods. The training curriculum should include instruction on programming as well as operating welding robots to advance automated and precise processes. The curriculum should teach students how to use predictive maintenance approaches together with methods to stop machine breakdowns for equipment protection. The implementation of AI algorithms in welding quality assessment enables their ability to identify defects as well as operate AI-based inspection systems within welding laboratories. Welding quality control receives improvement through AI and machine learning training which students need to cultivate for process optimization alongside their ability to handle welding data collection and analysis. The implementation of newer solutions will allow students to practice contemporary technological approaches consequently making them prepared. The Internet of Things (IoT) monitors gas levels and detects leaks through its cylinders which use IoT technology for gas welding to stop accidents. Welding machines should use IoT technology to implement real-time optimization of voltage and current and temperature adjustments. Sensors installed at welding stations will serve two purposes by monitoring operational performance and by spotting defects thus producing welds with enhanced quality. Students can learn welding techniques through Augmented Reality tools while receiving walking directions for each step of the process. Robotic welding systems need implementation to fulfil welding activities in a precise automated manner. The combination will enhance the accuracy level while minimizing errors from manual work. IoT sensors together with data analytics systems continuously check equipment states to detect welding failures before they occur. Welders must wear smart helmets with integrated sensors to track their safety while the supervisor administers remote health checks on the technological equipment at the work site. These advancements will transform welding education into a modernized structure that follows standards of Industry 4.0.

The development of faculty proficiency demands instructors to achieve competence in both Industry 4.0 technologies and contemporary teaching practices. The success of training programs depends on developing educational staff proficiency through courses that teach IoT and AI alongside robotics data analytics and automation so instructors can properly teach emerging technological content. Workshops that incorporate practical training with Industry 4.0 tools should be offered to train both educators about current technological advancements and allow them practice with the modern tools. These initiatives will enhance educational quality so faculty members acquire sufficient skills to deliver modern industry requirements to their students.

Industry 4.0 technological implementations can transform TVE through their capacity to empower intelligent campus administration and data-oriented managerial choices combined with cloud-based administration tools. The management of student tracking functions through automated attendance systems incorporating Radio Frequency Identification (RFID) or biometric authentication or facial recognition features allows for improved tracking capabilities and smart classrooms enabled with interactive whiteboards together with IoT-connected devices provide educational excellence. IoT-enabled asset tracking ensures efficient equipment usage and maintenance. There can be optimization by Big data and AI-driven analytics. It can optimize resource allocation, predict student dropout trends, and guide curriculum development. On the other hand, Cloud-based administration centralizes student records, automates admissions, fee management, and facilitates collaboration. Also, workforce management can be improved through AI-driven trainer performance analysis and cloud-based collaborative platforms. The curriculum can stay updated by AI-driven job market analysis, skill gap assessments, and real-time industry collaborations. Student engagement can be enhanced with AI-powered catboats and gratification tools for interactive learning. Block chain technology can ensure secure, immutable student certifications and academic records, enhancing credibility. Cyber-physical systems (CPS) in workshops enable smart workstations that optimize machinery performance and predictive maintenance. [4] Additionally, automation of administrative tasks, including fee management, report generation, and resource scheduling, can significantly improve operational efficiency. These innovations will modernize TVE, aligning them with Industry 4.0 and preparing students for the evolving technological things.

IV. METHODOLOGY:

According to Fortune Business Insights (2024), the global VR in education market was predominantly led by higher education institutions in 2022. VR has played a vital role in providing seamless learning opportunities, including student recruitment, fundraising, and immersive learning experiences. The vocational training sector is expected to experience the highest compound annual growth rate (CAGR), driven by VR's ability to simulate real-world work environments. This allows students to practice skills without the risks associated with high-stakes industries such as aviation, construction, and healthcare. Sanjeewa (2021) examined the use of big data analytics in vocational education, highlighting how collecting, tracking, and visualizing student data can provide valuable insights into learners' progress. This approach enables timely interventions to address risks of failure or dropout by analyzing data related to behavior, academics, and support needs. Integrating systems like Student Information Systems (SIS) or Learning Management Systems (LMS) with learning analytics allows providers to access real-time, individual-level data. Continuous data collection through student dashboards offers educators a quick overview of students' activities, facilitating prompt responses to emerging challenges.[20]

TAFE Queensland in Australia has pioneered the use of virtual reality (VR) to train students in trades such as plumbing, electrical work, and carpentry. This technology allows students to practice complex tasks within a safe virtual environment, enhancing their confidence and skills. In Canada, the Canadian Welding Association has adopted augmented reality (AR) to revolutionize welding training. AR simulations enable students to visualize welding techniques, thereby reducing errors and material waste. Singapore's Institute of Technology employs AI-powered tutors to develop personalized learning plans tailored to each student's strengths and weaknesses. Chiang et al. conducted a systematic review of AR applications in vocational training over a 20-year period from 2000 to 2020. Analyzing 80 relevant studies across various industries, the review indicated that AR improves vocational skills and is widely adopted in medical training, industrial maintenance, and assembly. Common tools include AR glasses, simulators, Unity3D game engine, 360° panoramas, and AR applications, which have demonstrated significant benefits. The research confirms that AR substantially enhances vocational training, especially in medical and industrial fields. Future research could explore integrating intelligent technologies such as AR glasses, simulators, and Unity3D to create more engaging learning experiences.At Guangzhou Light Industry Vocational School in China, ABB Robotics has supplied teachers with comprehensive educational materials, instructor training, and a variety of ABB robots. This initiative empowers students to develop essential skills and prepares them for careers in robotics-related industries. ABB also supports courses in Electromechanical Technology and Industrial Robot Technology, aiming to equip students for increasingly automated workplaces.[20]

The key skills essential in the Industry 4.0 era include a solid understanding of Information and Communication Technology (ICT) and the ability to work effectively with data. ICT knowledge encompasses core IT competencies, proficiency in operating smart devices like robots and tablets, and an understanding of machine-to-machine communication, cybersecurity, and data privacy. The ability to work with data involves processing and analyzing machine-generated information, interpreting visual data outputs, and utilizing basic statistical techniques for informed decision-making. These areas are prioritized due to the ongoing digital transformation across industries. While technical expertise remains important, it is relatively less emphasized and generally pertains to interdisciplinary and process-specific technical knowledge, particularly for maintenance activities. Additionally, personal skills such as adaptability, teamwork, communication, decision-making, and a commitment to lifelong learning are crucial for successfully navigating the rapidly evolving technological landscape.

India has a young population, with a median age of 28. Most people are under 35, but many do not have the skills needed for modern jobs. The percentage of skilled young people has increased from 34% to 51.3% in ten years. The government is working to improve skills and create jobs, knowing that people are key to economic growth and new ideas.

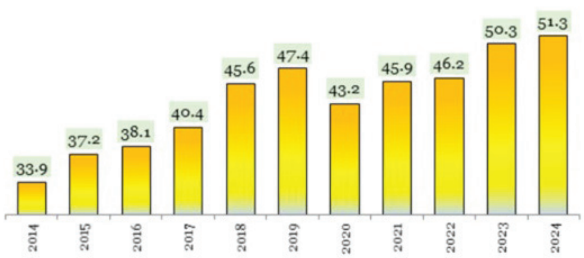

Fig. 4. Percentage employable final year or pre-final year students. [25]

To improve skills among youngsters,it is required to implement Industry 4.0 in TVE.The demand of AI workers for English speaking countries by occupation during 2019-2022 is as follows:

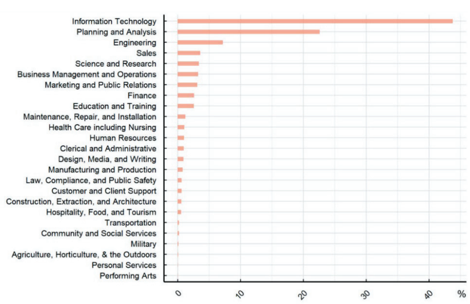

Fig. 5. Percentage of online vacancies advertising positions requiring AI skills in different occupation.[26]

The demand for AI professionals is steadily increasing across all industries, with the highest demand observed in the information technology sector. Therefore, implementing Industry 4.0 in the education sector is essential.

To facilitate seamless implementation and scalability, Industry 4.0 deployment plan should be structured into three distinct phases.

A. Phased Implementation Plan

The implementation of Industry 4.0 in TVE will follow a phased approach, beginning with phase 1.

Phase 1: Planning and Pilot Implementation (Months 1-6). This phase will involve conducting a needs assessment through surveys and interviews to identify infrastructure, curriculum, and faculty gaps. Here in the curriculum will be updated to integrate Industry 4.0 topics such as IoT, AI, robotics, and automation and training modules and materials will be developed. Infrastructure planning will identify necessary technologies like IoT kits, robotic arms, and 3D printers, followed by a pilot implementation in selected TVE, where faculty will be trained, and the new curriculum will be introduced. The outcome of this phase will be a clearer understanding of requirements and a tested implementation strategy.

Phase 2: State-Wide Rollout (Months 7-18) will focus on upgrading infrastructure across all TVE, including the establishment of smart labs and digital twin environments. Faculty training programs will be conducted, ensuring instructors are proficient in Industry 4.0 technologies. This updated curriculum will be fully implemented, incorporating hands-on training and industry projects. Collaborations with industries will be made strong by internships, expert lectures, and advisory boards, while student engagement will be enhanced through hackathons, workshops, and industry-recognized certifications. The expected outcome is the successful integration of Industry 4.0 across all TVE, equipping both students and faculty with essential skills.

Phase 3: Monitoring, Evaluation, and Continuous Improvement (Months 19-24) will establish a framework to track implementation progress, measuring key outcomes such as student employability and industry feedback. A structured feedback mechanism will be put in place to refine the curriculum and training based on industry needs and emerging trends. Continuous faculty training and curriculum updates will be chosen ensuring relevance and sustainability. Additionally, a scalable model will be developed to replicate the Industry 4.0 integration in any other vocational training institutes, with best practices shared across regions. This phase will ensure a sustainable and continually improving Industry 4.0 training ecosystem program in TVE, ultimately enhancing workforce readiness and employability.

B. Stakeholder Engagement

The successful implementation of Industry 4.0-enabled welding training in TVE requires identifying and engaging key stakeholders. Internal stakeholders include students, who are the primary beneficiaries, faculty responsible for delivering the training, TVE administrators overseeing implementation, and curriculum developers ensuring the welding curriculum aligns with industry advancements. There are external stakeholders comprise government agencies such as the Ministry of Skill Development, DGT (Directorate General of Training), and DVET (Directorate of Vocational Education & Training) [20]. They provide funding and regulatory support. Industry partners, including welding equipment manufacturers like Lincoln Electric and ESAB, along with automotive and construction firms, contribute or share expertise and technology. Some technology providers such as Siemens and Bosch supply Industry 4.0 tools like IoT devices, AR/VR systems, and robotics. Certification bodies like AWS and ISO-certified organizations assure training programs meet global standards, while local communities and NGOs benefit from the enhanced employability of TVE graduates. Clearly defining stakeholder roles and responsibilities facilitates effective collaboration. Students participate in training programs and provide feedback. Faculty offer training and continuously upgrade their skills. TVE administrators allocate resources and oversee project execution, whereas government agencies give financial and policy support. Industry partners give internships, live projects, and curriculum input, and technology providers supply and support smart welding equipment. Certification bodies validate training programs, ensuring graduates receive globally recognized credentials. Stakeholder engagement strategies include workshops and seminars to introduce Industry 4.0 concepts, regular meetings with a steering committee to monitor progress, and surveys to collect feedback for continuous improvement. Collaboration with industries is reinforced through advisory boards, student internships, and industry visits, ensuring that training remains relevant and aligned with real-world applications. All these coordinated efforts will drive the successful integration of Industry 4.0 technologies in TVE welding programs, fostering a future-ready manpower.

V. Case Study:

The user specific interlinkage is achieved through the interfaces/screens on the stations. In the further communication and utilization of the data, all the data is getting acquired in the IoT device, which generally is the Software solution data centre where the Big Data is getting compiled and distributed for its anticipated purpose of processing. The screens do not only support in terms of providing the set parameters based on the previous studies, but also used to acquire the production data, process as well as product parameters and the rejection patterns. It is the source for monitoring variations in current processes, based on the process and product parameters, in the later layers. The whole data is utilized and interlinked with introduction of Network Switch and Gateways. They perform the analysis and all the critical job which is intended from the system. This system can perform and dictate the output of the process by strong analytical tools with introduction of AI. The presence and possibility of integration with existing Enterprise Resource Planning (ERP) system can be achieved in the next layer or else, an integration mode is required to be developed for managing the data accommodation with ERP servers. The Manufacturing Execution System Server utilizes the data to monitor, trace, regularize and control the production ecosystem. Manufacturing Execution System (MES) processes the real time advice and passes it on to the next station, i.e. the Dashboard.

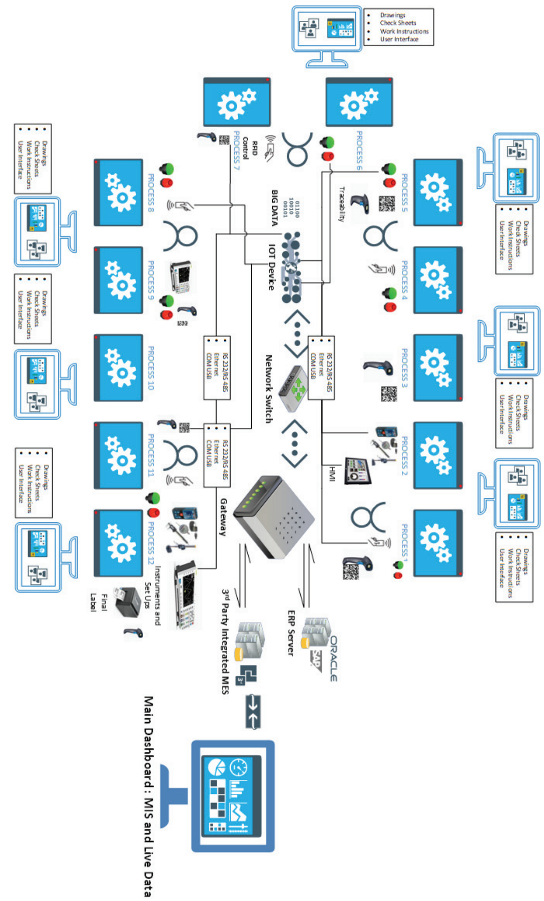

Fig. 6. The production order graphical representation

The main dashboard consists of all the requisite parameters and fields needed by the Production system to have a healthy and optimized system. The dashboard ensures to provide real time illustration of the data acquired as well as analysed across the different stages. Setting up the absolute process flow diagram along with all the possible variables helps to have the optimized architecture built up. The success of the Industry 4.0 is entirely dependent on the perfect capturing of the details and allowing the flexibility in the system to accommodate all the potential variations. There have been instances where the cost of the smart factory could be greatly saved with the efficient pre-definition of the architecture. The successful implementation of Industry 4. 0 in a smart factory relies on integrating multiple machines with sensors, PLCs, and HMIs to compile and analyse big data for process optimization. Ensuring a flexible system and proper data management is key to minimizing costs and maximizing efficiency.

Very few studies examine student competence levels directly or track longitudinal impact of new curricula.

1. Adoption Rate:

- 68% of TVET institutions have integrated at least one Industry 4.0 technology (e.g., IoT, AI, or robotics) into their curriculum.

- Source: UNESCO-UNEVOC Global TVET Trends Report, 2023

2. Faculty Training:

- 54% of technical staff in TVET colleges underwent training related to digital and smart manufacturing technologies.

- Source: ILO Skills for Industry Survey, 2022

3. Infrastructure Readiness:

- 47% of institutions reported having access to Industry 4.0 infrastructure such as simulation labs, CNC machines, or IIoT devices.

- Source: World Bank Skills Development Report, 2022

4. Student Engagement:

- Over 60% of enrolled students in technical diploma programs participated in projects involving Industry 4.0 tools (e.g., PLC programming, automation kits).

- Source: Asian Development Bank (ADB) Technical Education Monitoring Survey, 2023

5. Industry Collaboration:

- 35% of institutions established partnerships with smart manufacturing industries to provide internships and on-site training.

- Source: OECD TVET and Industry Partnership Review, 2022

6. Funding and Investment:

- On average, 22% of the annual budget of public TVET institutes is allocated to digital transformation and Industry 4.0 integration.

- Source: National Skills Development Corporation (NSDC) Annual Budget Report, 2023

7. Geographic Variation:

- Urban TVET institutions show a 72% adoption rate compared to 43% in rural areas.

- Source: Ministry of Skill Development and Entrepreneurship (MSDE), India, Regional TVET Analysis Report, 2023

VI. Results and Discussion:

A. *Comparative analysis of Pilot results:*

Learning Factories 4.0 in Germany conducted a three-phase study involving 63 vocational students. The study observed a 15% enhancement in technical skills, such as troubleshooting IoT systems, following practical training in cyber-physical production environments. Conversely, gains in multidisciplinary digital skills, including data analytics, were minimal, indicating a gap in the current curriculum. According to the Skill Shift Quantification report by the World Economic Forum, by 2025, 60% of core vocational skills are expected to evolve. The demand for analytical thinking is projected to rise by 19%, whereas manual troubleshooting skills are anticipated to decline by 12%. Reskilling initiatives that incorporate augmented reality simulations have successfully reduced skill gaps by 30% within manufacturing sectors.[22].

Implementation Frameworks and Pilot Outcomes include a phased adoption model in China's TVE, where a pilot phase lasting six months involved twenty institutes equipped with IoT-enabled welding robots and augmented reality maintenance simulators. The results showed a 25% reduction in training duration and an 18% increase in employment rates within smart factories. The state-wide scale-up involved an investment of $1.2 million per institute for smart laboratories, including 3D printers and digital twins. The return on investment demonstrated a 40% improvement in energy management efficiency through real-time sensor data analysis.[23]

Agile Integration at Singapore's Institute of Technical Education (ITE) involves the Skills Future Program, utilizing tools such as AI-driven diagnostics and cloud-based Manufacturing Execution Systems (MES). The program has achieved a 92% graduate employment rate and a 35% wage premium for roles augmented by AI.[24]

Comparative analysis of global models sources includes the World Economic Forum (2023) with its Future of Jobs Report, the German Federal Institute for Vocational Education (2022), the China Ministry of Education (2023) with its Industry 4.0 Pilot Analysis, and SkillsFuture Singapore Annual Review (2023).

TABLE I. Implementation Efficiency Metrics

Country	Model	Technology Focus	Key Outcomes
Germany	Learning Factories 4.0[22]	CPS, IoT, AR	15% increase in technical skills; 20% decrease in material waste
China	Pilot-to-Scale [23]	Robotics, Big Data	30% % increase in productivity; 25% faster skill acquisition
Singapore	SkillsFuture[24]	AI, Cloud, AR	92% employment; 40% wage growth

B. Survey:

Interview data of passout welder trainees from Industrial Technical Institute Peth, who used VR simulations during training and are now employed in companies. The methodology involved 30 participants who had passed out from Industrial Technical Institute with a welder trade, trained on VR, and are currently working at Mahindra and Mahindra. Data collection tools included an interview questionnaire, with ethical considerations such as obtaining consent and ensuring anonymity.

TABLE II. FINDINGS FROM SURVEY

Metric	Value	Source
Average reduction in onboarding time	42%	30 trainees
Reduction in weld defects (first month)	30%	
Employer satisfaction rate	90%	

The Monitoring & Evaluation (M&E) Program confirm the successful implementation and impact assessment of Industry 4.0 technologies in TVE. Its objectives are tracking progress in the integration of these technologies, measuring outcomes for students, faculty, and industries, identifying challenges during implementation, and facilitating continuous learning to refine the project and guide future initiatives. The program evaluates results in terms of skill development, employability, and industry relevance. Key performance indicators (KPIs) are categorized into input indicators (e.g., infrastructure readiness, trainer skills, curriculum alignment), process indicators (e.g., training activities, tool implementation, industry partnerships), output indicators (e.g., number of students trained, graduation rates, certifications, internships), and outcome indicators (e.g., employment rates, skills proficiency, industry feedback, adaptability to new technologies).

The M&E framework contains designing a monitoring plan with baseline data collection, real-time tracking, and evaluation periods, supported by tools like surveys, focus groups, and interviews. Proper roles and responsibilities are assigned to stakeholders such as DVET, M&E committees, TVE trainers, training officers, and external evaluators. Data collection does combine quantitative metrics (e.g., enrolment, job placements) and qualitative feedback from students, trainers, and employers. Regular reporting system, including monthly, annual, and final reports, ensure transparency and accountability. There are risk management strategies address potential challenges like resistance to change or resource shortages.

The evaluation approach includes formative evaluation for real-time program refinement and summative evaluation to assess overall effectiveness. Outcome and impact assessments focus on employability tracking, industry penetration, and continued learning among graduates, ensuring the program's long-term success and alignment with Industry 4.0 demands. This comprehensive M&E framework ensures that the integration of Industry 4.0 technologies in TVE is effective, scalable, and impactful for all.

VII. CONCLUSION:

After the implementation of Industry 4.0 technologies in TVE is expected to yield immediate, short-term, and long-term outcomes, transforming vocational education and aligning it with modern industrial demands. In the immediate term (0-6 months), expected outcomes include infrastructure modernization with cutting-edge tools like 3D printers, robotics labs, and IoT devices, alongside the adoption of smart classrooms and e-learning platforms. The new curriculum will be updated to include Industry 4.0 topics such as automation, AI, and cyber-physical systems, at the same time trainers will undergo upskilling programs to effectively teach these technologies. Students will get initial awareness of emerging tools, and early industry partnerships will provide real-world insights and internships to them.

As in the short term (6-12 months), students will develop practical skills in robotics, IoT, and automation, supported by hands-on experience with advanced machinery. This will provide higher employability, increased placement rates, and industry-recognized certifications. Collaborations with industries may deepen, with feedback loops ensuring curriculum relevance and the implementation of industry-specific projects. Trainers will obtain specialized knowledge and confidence in delivering Industry 4.0 content, enhancing the overall quality of technology education.

In the long term (over about 1-5 years), TVE will acquire sustained adoption of Industry 4.0 technologies across all trades, fostering adaptability to future industrial shifts. Graduates will have future-ready skills, aligning with global standards and contributing to economic growth through enhanced productivity and efficiency. The region will attract global investment, as students will benefit from engaging, practical learning experiences, leading to higher satisfaction and retention rates. Robust industry-academia linkages will assure continuous curriculum alignment with market demands, offering strength to national competitiveness and establishing TVE as models for self-sustaining modern educational systems. This holistic transformation will help the workforce to stand in the era of Industry 4.0, driving innovation and economic progress that we expect.

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