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The convergence of Education 4.0 and Industry 4.0: a Twin Peaks model

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Abstract

Purpose – This paper explores the convergence of Education 4.0 and Industry 4.0 and presents a Twin Peaks model for their seamless integration.

Design/methodology/approach – A high-level literature review is conducted to identify and discuss the important challenges and opportunities offered by both Education 4.0 and Industry 4.0. A novel Twin Peaks model is devised for the convergence of these domains and to cope with the challenges effectively.

Findings – The proposed Twin Peak model for the convergence of Education 4.0 and Industry 4.0 suggests that the development of these two domains is interdependent. It emphasizes ethical considerations, inclusivity and understanding the concerns of stakeholders from both education and industry. We have also explained how continuous incremental adaptation within the proposed Twin Peaks model might assist in addressing concerns of one sector with the opportunities of the other.

Originality/value – First, Education 4.0 and Industry 4.0 are reviewed in terms of opportunities and challenges they present. Second, a novel Twin Peaks model for the convergence of Education 4.0 and Industry 4.0 is presented. The proposed discovers that the convergence is adaptive, iterative and must be ethically sound while considering the broader societal implications of the digital transformation. Third, this study also acts as a torch-bearer for the necessity for more research of this kind to guarantee that our educational ecosystem is adaptable and capable of producing the skills required for success in the era of IR4.0.

Keywords Digital transformation, Education 4.0, Industry 4.0, Twin Peaks model, E-manufacturing

Paper type Research paper

1. Introduction

The advancements in emerging technologies, evolving social needs and the comparative readiness to tackle future pandemics (like COVID-19) demand reshaping the teaching–learning world. This demand for a profound transformation is further intensified by the fact that the traditional classroom model is no longer sufficient to prepare students for the challenges and opportunities of the 21st century (Till *et al.*, 2016, Genesis *et al.*, 2023; Schwab, 2017). The term Education 4.0 (ED4.0) is frequently used to describe this paradigm shift in education. All the three key stakeholders in education – students, teachers and institutions – are impacted by this change. The learners are empowered with digital tools and resources (Alexander *et al.*, 2019), educators leverage artificial intelligence (AI) and data analytics to personalize instruction (Gašević *et al.*, 2015), and institutions adapt to a dynamic landscape where lifelong learning and interdisciplinary skills are paramount (UNESCO Institute for Lifelong Learning and Shanghai Open University, 2023). Although, ED4.0 encourages personalized and collaborative learning and provides better access to education through

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different E-learning platforms (Hodges *et al.*, 2020); however, the use of advanced technologies (like AI, machine learning and big data analytics) also poses challenges related to data privacy, security and adaptability (Avidov-Ungar and Magen-Nagar, 2014; Luminita, 2011). This in turn calls for the development of new technologies as well as the improvement of already existing ones.

The fourth industrial revolution (IR4.0), also known as Industry 4.0, aims to transform industrial manufacturing and production operations through the integration of cross-cutting digital technologies such as the Internet of Things (IoT), AI and big data analytics. IR4.0 promises to create smart factories and efficient supply chain networks to fulfill ever-growing customer demands. IR4.0 thrives to increase productivity, reduce costs, improve quality and promote sustainable manufacturing practices (Schwab, 2017; Kagermann *et al.*, 2013). While keeping its promises, IR4.0 also presents novel challenges related to cybersecurity, workforce skills and ethical repercussions of using advanced technologies in modern industries (Lu, 2017; Culot *et al.*, 2019). The World Economic Forum's report of future jobs (Saadia *et al.*, 2020) states that 50% of the employees need to be retrained and upgraded in order to fulfill IR4.0 demands. This is due to the increase in adoption of new technologies and the change in how human and machine work together. The lack of skills in the workforce is even seen as an imminent threat, and the successful deployment of IR4.0 depends on ongoing operations and management improvements (Behie *et al.*, 2023; Rossella Pozzi and Secchi, 2023). Several studies like (Li, 2022; Verma and Venkatesan, 2023; Ozkan-Ozen and Kazancoglu, 2022) have also highlighted the need of reskilling and upskilling of the workforce to meet the requirements of IR4.0. The reskilling and upskilling must be centered on lifelong learning with affordable anywhere anytime learning platforms in order to close the widening skill gap. Adoption of ED4.0 appears to be crucial to foster critical and analytical thinking and to advance the most recent problem-solving skill so that learners are better equipped to handle challenging real-world issues.

Industry 5.0 (IR5.0) is an additional upgraded concept that is introduced based on the concepts and technologies of IR4.0 (Huemer, 2020). Instead of trying to replace IR4.0, IR5.0 uses improved IR4.0 technologies to concentrate more on human-centric solutions. For the sake of this study, we do not distinguish between IR4.0 and IR5.0 technologies because establishing the groundwork for ED4.0 and IR4.0 convergence will benefit IR5.0 as well.

This study investigates the convergence of IR4.0 and ED4.0, which is of paramount importance in today's rapidly evolving technological landscape. IR4.0 has the potential of increasing productivity, reducing operational costs and realizing innovative business ideas by applying smart technologies. Simultaneously, ED4.0 represents a transformation in the learning and skill development. By using the power of digital technologies it prepares individuals for a job market that is driven by IR4.0.

1.1 Contributions

This paper contributes by thoroughly investigating the convergence of IR4.0 and ED4.0, recognizing the pivotal role this intersection plays in the rapidly evolving technological landscape. The contribution of this study is a twofold.

(1) Firstly, we have presented the crucial challenges and potential benefits of ED4.0 and IR4.0 in realizing convergence of these two paradigms for bridging the gap between academia and industry.

(2) Secondly, a Twin Peak model is presented and discussed how the advantages of one can be contacted to deal with the challenges of the other in order to achieve the successful convergence and full benefits of ED4.0 and IR4.0. Realization of this Twin Peak model can enable us to set foundations for educational systems that will ensure the readiness of a lifelong learning to meet the demands of a technology-driven workforce.

This study also acts as a torch-bearer for the necessity for more research of this kind to guarantee that our educational ecosystem is adaptable and capable of producing the skills required for success in the era of IR4.0.

1.2 Outline

Next section summarizes the existing literature on ED4.0 by describing the important opportunities and challenges while Section 3 outlines the significant challenges and opportunities faced by IR4.0. Section 4 presents the Twin Peaks model for the convergence of ED4.0 and IR4.0. Section 5 discusses resolution of challenges related to both the sectors under the proposed model. Section 6 concludes the study.

2. Understanding Education 4.0

In this section, we explore ED4.0 by highlighting the opportunities it brings from personalized learning to global connectivity. The critical challenges such as digital skills gaps and ethical concerns that must be coped with for full potential of this educational paradigm shift are also addressed.

2.1 Opportunities of Education 4.0

Figure 1 depicts the important challenges and opportunities offered by the ED4.0. The key opportunities, showing how the ED4.0 is transforming education and contributing to sustainable employability, are specified below:

2.1.1 Personalized learning and skill development. The goal of personalized learning is to create a learning plan for each student that takes into account his/her needs, interests, skills and strengths (Zhang *et al.*, 2020). It boosts confidence in students by allowing them to set personal goals, taking pleasure in learning and learn at their own pace. ED4.0 promotes personalized learning and encourages educators and institutes to consider individual students' needs, preferences and learning styles while setting up courses. The extensive approach of personalize learning is made possible through advanced learning analytics, adaptive platforms and digital content customization. It also enables individuals to identify novel skills in-demand, set their development path and progress at their own pace and convenience (Expósito López *et al.*, 2019). ED4.0 with personalized learning is opening new

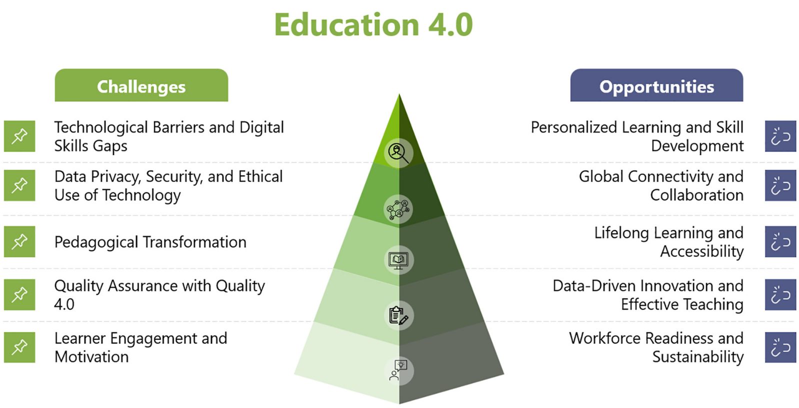

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Figure 1. Challenges and opportunities of ED4.0

prospects of employment and career in various sections like programming, marketing and management, etc.

2.1.2 Global connectivity and collaboration. The way employees used to work in on-site workplaces has changed as a result of information and communication technologies (ICTs). Through these technologies, millions of people are collaborating in virtual (home) offices to complete thousands of international projects (Raja *et al.*, 2013).

Education, like other sectors (health, for example (Li *et al.*, 2021)), has also been significantly affected by the proliferation of ICTs and the education institutes are demanded to prepare students for the global labor market. As a result, the concept of collaborative learning flourished wherein the learners are engaged in virtual cross-cultural teams using convenient affordable learning tools (Laal and Ghodsi, 2012). ED4.0 uses different online platforms to connect students and teacher globally. It is now possible to conduct cross-cultural interactions, work on collaborative projects in virtual classrooms and promote global awareness.

2.1.3 Lifelong learning and accessibility. The rapid increase in knowledge-creation and sharing necessitates lifelong learning to continuously improve our skills required to catchup with the advances in the technology. Lifelong learning is one of the most critical skills of the 21st century (Romero, 2015; Matsumoto-Royo *et al.*, 2021). ED4.0 promotes lifelong learning by making education accessible throughout one's life. Online courses arranged as massive open online courses (MOOCs), microdegrees and other digital resources provide opportunities for learners to update their knowledge and skills continuously. By removing physical and geographic barriers, this accessibility increases access to education for a larger and more diversified population.

2.1.4 Data-driven innovation and effective teaching. One of ED4.0's fundamental components is learning analytics. By utilizing data to support student-centered learning, it is also used to enhance teaching and learning in ED4.0. Data can be analyzed by educators for informed decisions, pinpoint areas where students need assistance and modify their pedagogical approaches. This data-driven methodology produces dynamic learning experiences and more effective teaching strategies. Data collected through various smart devices and sensors are analyzed with pre-trained AI models to know more about the motivation, engagement and learning behavior of the students (Ciolacu *et al.*, 2019).

2.1.5 Workforce readiness and sustainability. In ED4.0, learning is aligned with the evolving needs of the job market, which ensures that the learners have the knowledge and skills required for IR4.0 professions. In turn, this alignment improves employability and gets people ready for the requirements of the digital workforce.

Additionally, ED4.0 contributes to environmental sustainability by reducing the environmental footprint associated with the traditional education methods. ED4.0 transforms education for sustainable development by preparing students for collaborating on global interdisciplinary environments (Matsumoto-Royo *et al.*, 2021). The challenges of satisfying the requirements of sustainable development within the framework of ED4.0 have been covered in several studies like (Brudermann *et al.*, 2019), along with ways for educational institutions to deal with these challenges.

2.2 Challenges of Education 4.0

Along with the exciting opportunities, ED4.0 also presents significant challenges in the field of learning and knowledge sharing as shown in Figure 1. The rest of this section is dedicated to specify key issues that must be resolved in order to take full advantage of the potential provided by ED4.0.

2.2.1 Technological barriers and digital skills gaps. The increasing adoption of cutting-edge technologies in the ED4.0 is creating technological barriers and putting instructors with lack of essential digital literacy at a disadvantage (Bates, 2019). It is quite challenging to guarantee that all educators and learners acquire necessary technology abilities and that they even have access to the required tools and technologies. According to the European Commission's report on Education and Training Monitoring 2020 (European Commission and Directorate-General for Education, 2020), 48% of the students in Italy could not participate in the distance learning due to either lack of resource (devices and Internet) or difficult home conditions. The reports also states that only 49.1% of the instructors had formal ICT training. This digital divide leads to a digital skills gap which prevents the effective implementation of digital learning methodologies required for full potential of ED4.0 (Selwyn, 2016). Adequate training and support for both educators and learners is vital for bridging this gap.

2.2.2 Data privacy, security and ethical use of technology. For personalized learning, individual milestones setting and customized course contents, ED4.0 relies on the extensive use of students' data collected through learning management systems and related tools. Such extensive use of data for learning analytics necessitates robust data privacy and security measures (Reidenberg and Schaub, 2018). For a secure and supportive learning environment, the responsible use of technology with assurance of data privacy and security is decisive. However, protecting students' personal information and ensuring compliance with data protection regulations are demanding.

ED4.0 requires a multifaceted approach involving all stakeholders (educators, learners, institutes and policymakers) to negotiate the balance between data insight and privacy and to discourage cyberbullying and digital plagiarism.

2.2.3 Pedagogical transformation. In the context of knowledge creation and sharing, ED4.0 marks a significant change in the traditional educational settings. The new paradigm embarks a student-centric technology-driven teaching approach, where the students are active learners instead of passive listeners and teachers are equipped with latest technologies. This transformation not only demands a change in instructional methodologies and materials but also requires a commitment to continual professional development (Siemens and Tittenberger, 2013). This continual life-long learning is essential to keep pace with the rapidly evolving technologies, innovative pedagogical techniques and the shifting educational landscape (Nguyen, 2019). For instance, the release of ChatGPT and other LLM-based applications has made it more difficult to assess learners' understanding of the contents and motivate them to learn it. At the same time, such application can be used for writing personalized lesson plans and generating ideas for classroom activities endorsing a positive impact on the teaching–learning process (Montenegro-Rueda *et al.*, 2023).

2.2.4 Quality assurance with Quality 4.0. Quality measurement and assurance of processes followed in ED4.0 with the traditional methods is not feasible. Along with the industry and education, the quality assurance has evolved from inspection to discovery. Term Quality 4.0 is used to represent the digitization of traditional quality approaches for assessment and assurance of quality matrices (Maganga and Taifa, 2023).

The proliferation of online courses makes it even more difficult for the institutes and educational authorities to monitor and assess the quality of the contents and instructional materials. The challenge is not only in evaluating the contents but also in verifying the accessibility, engagement and interactivity of these materials. Studies like (Alzahrani *et al.*, 2021) indicate that the adoption of Quality 4.0 for higher education institutes is still limited due to the fragmented processes, unavailability of data and required resources. Furthermore, quality assurance in ED4.0 goes beyond only adhering to academic standards. It explores how well digital materials work to encourage learning. Another aspect of quality assurance in ED4.0 is the challenge in using virtual labs with E-learning platforms for substituting physical labs for STEM courses (Ahmad and Sarjoughian, 2023).

2.2.5 Learner engagement and motivation. Instructional paradigm of ED4.0 is dependent on technology integration. Access to multiple applications, social media platforms and online content make it challenging for learners to maintain their focus on educational tasks (Vonderwell and Zachariah, 2005). Some of the key elements influencing learner's engagement and motivation, as indicated in (Kahn *et al.*, 2017), are students' multitasking patterns, platform interface and instructor interaction, familiarity with technology being used and information overload. Designing interactive and engaging online courses and activities short quizzes and immediate feedback on students' responses can lead to increased motivation.

3. Unpacking Industry 4.0

In this section, we review the literature on IR4.0 by emphasizing the advantages it offers, such as increased automation and productivity, labor involvement and global connectivity. The major obstacles that must be overcome for this shift in the industrial paradigm to succeed, such as cybersecurity threats and vulnerabilities, interoperability and standardization, are also covered. The significant opportunities and challenges provided by the IR4.0 are shown in Figure 2.

3.1 Opportunities of IR4.0

The primary opportunities that demonstrate how IR4.0 is changing business and assisting in sustainable production are detailed below.

3.1.1 Automation and efficiency. Under the umbrella of IR4.0, automation of various manufacturing/development processes is carried out using technologies like robotics, IoT and AI. A report from German national academy of science and engineering (Kagermann *et al.*, 2013) reveals that the integration of IR4.0 technologies, particularly IoT, can optimize operational processes. IoT-enabled devices and sensors can monitor resource utilization and equipment maintenance needs in real-time allowing proactive adjustments. Automation with latest AI and digital twin technologies can assist in minimizing human errors significantly (Brynjolfsson and McAfee, 2014). This leads to increased operational efficiency, reduced human error and cost savings.

3.1.2 Customization, personalization and globalization. IR4.0 has made it possible to mass customize for as many users as possible through requirements refinement and modular development (Kotha and Pine, 1994). Higher level of customer satisfaction is achieved by tailoring products to individual needs for better market competitiveness. Understanding of

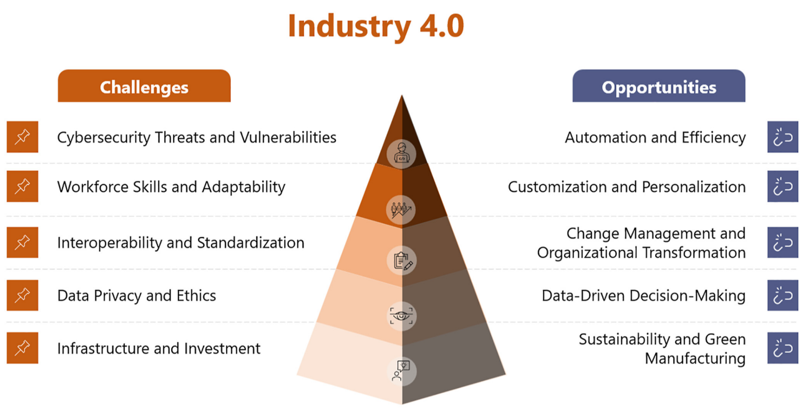

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Figure 2.
Challenges and opportunities of IR4.0

the customers' behavior is also explored through data-driven insights, which ultimately helps in fulfilling customer requirements in a constantly changing business world (Du *et al.*, 2003). With the help of the Internet's global reach and state-of-the-art IR4.0 technology, e-manufacturing enhances the manufacturing companies' ability to contact customers anywhere, at any time (Cheng and Bateman, 2008).

3.1.3 Change management and organizational transformation. According to a survey research by McKinsey & Company (Dominik *et al.*, 2016), most of the business leaders (67% from Germany, 74% from Japan and 44% from the USA) are confident about their readiness for the transition to IR4.0 and its advantages. The majority of businesses have already given specific tasks to the appropriate authorities and rules. Integration of advanced enabling technologies like robotics, customized manufacturing and tools for data collection and management had made it possible (Rüßmann *et al.*, 2015; Popkova *et al.*, 2019). Companies are drawn to this effective digital transition because it offers a number of competitive benefits. In order to help enterprises make the transition to IR4.0 smoothly, the maturity models are also investigated (Gökalp *et al.*, 2017).

3.1.4 Data-driven decision-making. In IR4.0, effective decision-making is ensured by the data collected through different sensor, and IoT devices interconnected together to form a network. The ability to analyze insights from this big data for better resource management has improved and encouraged the data-driven decision-making. With advance data warehousing and mining techniques, data analytics has already proved its worth in different businesses like supply chain (Lee and Mangalaraj, 2022). The real-time information is helping the decision-makers to identify trends and areas of potential improvement. Predictive maintenance, a proactive maintenance approach powered by data analytics, reduces downtime by identifying machine failures before they occur and enhances productivity (Zonta *et al.*, 2020). Market data insights also assist in identifying customer preferences and market trends and thus, staying ahead of the competitors.

3.1.5 Sustainability and green manufacturing. One of the remarkable opportunities presented by IR4.0 is its potential to drive sustainability and green manufacturing practices. IR4.0 technologies are not only employed for waste reduction but also for reducing environmental impact of the production process and align with global sustainability goals. Industries are empowered to become more agile, competitive and sustainable with eco-friendly policies and practices. Energy efficiency is improved with precise energy management based on the data collected from IoT sensors and real-time analytics (Mao *et al.*, 2021). 3D printing as a key technology in IR4.0 allows the production of lightweight and efficient components with minimum material waste (Malik *et al.*, 2022).

3.2 Challenges of IR4.0

The remainder of this section presents some of the important challenges faced by IR4.0, as shown in Figure 2.

3.2.1 Cybersecurity threats and vulnerabilities. In IR4.0, integration of heterogeneous devices and systems also increases the risk of vulnerabilities for cyberattacks. This hyperconnectivity has exposed industries to a different potential risks, including data breaches, ransomware attacks and IoT device vulnerabilities (Ervural and Ervural, 2018; Dawson, 2018). Different aspects of cyber security in IR4.0 have been extensively researched. For example, a review by Corall *et al.*, looks into the impact on business performance of the loss of data's confidentiality, integrity and availability in networked systems (Corallo *et al.*, 2020). Due to the diverse nature of cyberattacks in the IR4.0, in order to address IoT device vulnerabilities, supply chain assaults and insider threats, a multifaceted strategy is required.

3.2.2 Workforce skills and adaptability. As technology landscape of IR4.0 is expanding, the existing workforce may lack the necessary skills to operate, maintain and leverage these advanced systems effectively. This skills gap has a negative impact on the potential utilization of these technologies in various industries. Change in workforce dynamics requires more sophisticated interactions between human and machines (Karacay, 2018). Workers must learn to interact with and supervise automated systems effectively. For complex IR4.0 systems, technologies like augmented reality (AR), virtual reality (VR) are examined to enhance understanding and effectiveness of the operating environment (Ras *et al.*, 2017). Industries must provide opportunities for career growth, flexibility and a work environment, which supports continuous learning.

3.2.3 Interoperability and standardization. According to a recent Huawei estimate (Xu, 2023), there will be 40 bn smart devices and 100 bn connections by 2025. These devices are produced by numerous manufacturers following proprietary protocols and standards. This diversity poses great challenges in ensuring the compatibility and interoperability among the devices.

Despite the introduction of reference architectures like Reference Architecture Model for Industry 4.0 (RAMI 4.0) and others that are based on RAMI 4.0, it is still difficult to guarantee seamless interoperability in all areas (semantic, structural, syntactic and system) for developing IR4.0 (Sun *et al.*, 2020). Global standardization is critical to address the interoperability challenges in dynamic reconfigurable systems in IR4.0 (Ahmad, 2023; Lelli, 2019). Compatibility can be improved by establishing industry-wide standards enabling the devices to exchange data and a secure understandable way.

3.2.4 Data privacy and ethics. In IR4.0, the data-driven innovation, management and decision-making also presents challenges of data privacy, ownership and ethical use. Data becomes vulnerable to exploitation as it moves over the network from collection and transmission to storage and analysis (Jose Ramon Saura *et al.*, 2022). Similar to ED4.0, the IR4.0 has substantial challenges in balancing data use and privacy protection. To address these difficulties, regulations and ethical standards must change. Additionally, as data are frequently gathered and processed across connected supply chains, data management becomes more and more difficult. Raptis *et al.* (2019) identified some of the key difficulties in the data management in IR4.0 as efficient data transmission with minimal delays, data distribution across clouds and dynamic data security. For the purposes of defining data ownership, access rights and stakeholder duties, clear legal frameworks and agreements must be established.

3.2.5 Infrastructure and investment. Transitioning to IR4.0 requires substantial investments in new technologies, infrastructure and manpower. Financial constraints may prevent small and medium-sized enterprises from upgrading to the required infrastructure (Masood and Sonntag, 2020). Ensuring fair access to IR4.0 capabilities across countries and industries is a challenge. This challenge can further propagate and may create competitiveness gap. Larger companies with more resources might advance more quickly than the SMEs (Elhusseiny and Crispim, 2022).

Addressing these challenges is fundamental for the successful implementation and growth of IR4.0.

4. Twin Peaks model for the convergence of Education 4.0 and Industry 4.0

The emergence of ED4.0 and IR4.0 represents an important transformation in the way we approach both learning and work in the current digital age. In the previous sections, we have presented the opportunities and challenges of ED4.0, with its focus on personalized learning, lifelong education and global access to knowledge. Simultaneously, we have explored the transformative potential of IR4.0, with its smart manufacturing, data-driven processes and automation, while acknowledging the heightened cybersecurity threats that come with it. However, what makes these paradigms truly transformative is the convergence that occurs at their intersection. The convergence of the ED4.0 and IR4.0 can be viewed as a Twin Peaks model originally developed by Bashar Nuseibeh for software requirements and architecture (Nuseibeh, 2001). We believe that ED4.0 and IR4.0 are weaving together and hence, must be investigated together for incremental research and development.

The proposed Twin Peaks model emphasizes that the convergence depends equally on ED4.0 and IR4.0. As depicted in Figure 3, the model distinguishes between ED4.0 peak and IR4.0 peak as two distinct entities. Each peak represents different but interconnected aspects of the convergence. While IR4.0 peak symbolizes the difficulties and opportunities associated to the industry element of the convergence, ED4.0 peak represents those relating to education. The two-headed arrow in the center denotes that the successful convergence is an iterative process of improvement and application of knowledge gained while developing simultaneously. Applying the Twin Peaks model to the convergence of ED4.0 and IR4.0 also involves aligning the goals and requirements of both domains to create a cohesive educational ecosystem that leverages IR4.0 technologies for enhanced learning and workforce readiness. The model's level of convergence ranges from society to the application-level, with specific demands for each stakeholder.

4.1 Ethical and societal considerations

The ethical and societal considerations surrounding the convergence of ED4.0 and IR 4.0 are critical for ensuring responsible and inclusive technological advancement. Establishing an ethical framework that directs the integration of cutting-edge technology into educational institutions and enterprises is crucial in the context of ED4.0 and IR4.0 convergence. This framework must address issues like data privacy, ensuring equity in access to education and job opportunities and promoting the responsible use of technologies.

The Twin Peaks model also promotes considering broader societal perspectives while converging ED4.0 and IR4.0. It aims to enhance inclusivity and diversity to enable all segment of society to benefit from the technological advancement. Individuals with diverse backgrounds and abilities must have equal access to education and career opportunities.

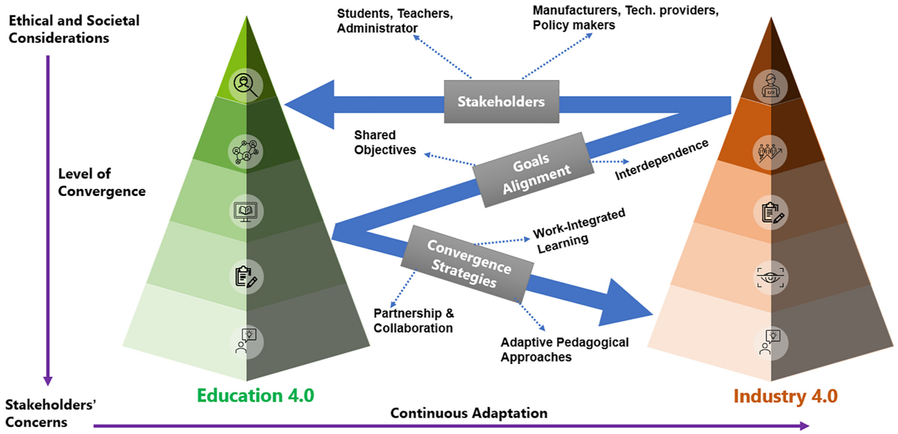

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Figure 3.
Twin Peaks model for the convergence of ED4.0 and IR4.0

4.2 Understanding stakeholders' concerns

Understanding the concerns of key stakeholders in the convergence of ED4.0 and IR4.0 is essential for successful integration. From the ED4.0 side *students* are concerned about the access to quality education with advance technologies and personalized learning experience. They also need to prepare for a rapidly evolving job market. *Teachers* are concerned about improvement in the pedagogical methods and effectively integrating technology into their teaching practices. To provide high-quality education, they also look for professional development opportunities and assistance with digital literacy. As the third import stakeholder in ED4.0, *administrators* focus on creating an educational ecosystem that facilitates lifelong learning opportunities.

From the IR4.0 side, *manufacturers* would like to develop their workforce to ensure their capabilities of operating and maintaining advanced technologies. They are also enthusiastic about using automation and digitalization to enhance productivity and quality for competitive advantages. *Technology providers* focus on developing and delivering the tools and solutions needed to support IR4.0. They want to lead technological innovation and ensuring compatibility with the existing systems as well as dealing with cybersecurity concerns. Finally, the *policymakers* are concerned with creating an environment for the industrial innovation and competitiveness. They demand for regulatory frameworks for technology adoption in alignment with the educational systems economic growth and sustainability.

4.3 Goals alignment

For ED4.0 and IR4.0 to work together, identification of common objectives is important so that both the sectors can work jointly to achieve these objectives. These shared goals serve as a bridge between education and industry, encouraging collaboration. For example, one common objective is to prepare a future-ready workforce. Education institutions can upgrade their curriculum and teaching methods to equip students with the required skills and knowledge. At the same time, the industries may invest in workforce development programs to ensure that employees are ready to operate and manage advanced technologies in IR4.0.

The Twin Peaks model recognizes that the challenges and advancements in ED4.0 peak and IR4.0 peak are interdependent. Changes and progress in one domain can significantly impact the other. This interdependence demands a holistic and comprehensive approach for the convergence of these two domains. Advancements in digital learning technologies within the ED4.0 peak can lead to better skilled graduates who are more prepared for adapting to the practices of IR4.0. Conversely, the implementation of automation and smart manufacturing practices in IR4.0 peak may influence the skills and knowledge that educational institutions need to teach their students.

4.4 Convergence strategies

The Twin Peaks model aims to promote establishing convergence strategies for harmonious relationship between ED4.0 and IR4.0. Partnerships between educational institutions and industries are at the core of convergence. These partnerships set foundation for collaboration allowing educational ecosystem evolve in relation with the evolving needs of the industries. Collaboration may result in the co-design of curriculum, where the educational programs are developed in consultation with the industry experts. The curriculum is designed to integrate real-world problems, ensuring that students receive education that is relevant to the needs of employers.

Provision of work-integrated learning experiences with practical applications is an essential element of the convergence. Such experiences can be of various forms, such as internships, apprenticeships or project-based learning. The hands-on exposure to industry practices, under such experiences, allows the learners to apply theoretical knowledge in the practical contexts.

Convergence strategies under the Twin Peaks model also encompass the adaptive pedagogical methods. Educators and trainers must adopt teaching approaches that promote critical thinking, problem-solving, digital literacy and adaptability. Students are transformed into active learners instead of passive listeners through group discussions, case studies and hands-on projects.

4.5 Continuous adaptation

In order to remain effective, the convergence under the Twin Peaks model, need to evolve continuously with changes in both the domains. The convergence can be evaluated by creating feedback loops involving various stakeholders including educators, students, industry professionals and technology experts. By gathering insights and feedback, the convergence can be fine-tuned. As shown in Figure 3, the Twin Peaks model is based on iterative approach for adapting changes effectively. The convergence of ED4.0 and IR4.0 should be adaptable enough to take advantage of new advancements in tools, technologies and teaching approaches. The approach of iterative refinement also guarantees that the convergence remains adaptable to incremental modifications and that the stakeholders have adequate time to plan and assess the adjustments.

5. Advantages of using the Twin Peaks model

The proposed Twin Peaks model provides a structured approach to aligning and converging ED4.0 and IR4.0. This section discusses the advantages of applying this model by explaining how the opportunities can be used to address challenges in both areas.

5.1 For Education 4.0

The Twin Peaks model can help address ED4.0 issues (shown in Figure 1) with the use of IR4.0 technologies.

Technological barriers and digital skill gap: Technological barriers can be surmounted with the help of IR4.0 technologies like AR and VR. Teachers may create immersive learning experiences by incorporating them into the classroom settings, which increases the engagement of both teachers and students with technology usage. Positive technological adaption for IR4.0 technology-based learning management systems and their usefulness has already been investigated in studies like (Jain and Jain, 2022; Moraes *et al.*, 2023).

Privacy, data security and ethical use of technology: Teaching ethical and responsible use of technology can be enhanced through IR4.0 technologies. Digital tools integrated into the curriculum can create real-world scenarios that teach students about responsible digital behavior and the consequences of unethical actions. Most of the IR4.0 technologies emphasize robust cybersecurity measures and data encryption. For example, through blockchain technology and secure data handling protocols, students' personal data can be safeguard.

Pedagogical transformation: Under the Twin Peaks model, advanced IR4.0 analytics and adaptive learning technologies can assist educators in tailoring learning process to individual student needs. Thus, facilitating the pedagogical transformation from traditional teaching to personalized, data-driven approaches. To minimize digital divide, IR4.0 technologies (e.g. cloud computing, open-source software and affordable hardware) enable development of low-cost, accessible educational tools and platforms.

Learner engagement and quality assurance: AI-driven quality monitoring can assess the effectiveness of educational materials and courses. The quality of digital resources can be enhanced in real-time with continuous monitoring and stakeholders' feedback. Technologies like gamification and interactive simulations can improve learners' motivation and engagement.

5.2 For Industry 4.0

The concept of Twin Peaks model allows the IR4.0 difficulties depicted in Figure 2 to be gradually addressed through the application of ED4.0 opportunities.

Cybersecurity concerns and ethics: ED4.0 can play a fundamental role in addressing cybersecurity challenges by offering specialized training programs in cybersecurity. These programs can educate professionals on the latest threats and defenses towards ensuring industries have skilled cybersecurity experts. Enhanced digital literacy and ethical data handling are key components of ED4.0. By including ethical considerations in the curriculum, students can develop a strong understanding of data ethics and privacy.

Skilled workforce shortage and interoperability: The shortage of a skilled workforce can be mitigated by the personalized and continuous learning approach of ED4.0. Online courses, microcredentials and lifelong learning opportunities can help workers acquire new skills and stay updated with the industry trends. E-learning platforms can be tuned to include interdisciplinary courses and group projects to expose students to real-world interoperability problems.

Infrastructure and investment: ED4.0 can offer courses and programs on gradual implementation and cost-effective technology implementation strategies. Change management can be facilitated by educating on adaptability and soft skills. Learners are encouraged to be open to change and educators use the innovative teaching methods to foster adaptability.

6. Conclusion

Industry 4.0 and Education 4.0 both provide fascinating possibilities and challenging situations. In the current digital era, the convergence of these two domains represents a revolutionary change in both education and industry. A Twin Peaks model is proposed for the convergence of Education 4.0 and Industry 4.0. It emphasizes that the convergence is adaptive, iterative and must be ethically sound while considering the broader societal implications of the digital transformation. Convergence alignment with continuous incremental adaptation can guarantee to equip individuals with the skills needed to thrive in the technology-driven era of the fourth industrial revolution and beyond. Depending on the organization, different implementation details for Twin Peaks apply. More research in this area is advised, as case-by-case analysis is needed to actualize the proposed Twin Peaks model for the implementation specifics.

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