DiTwin

www.ditwin.eu

Handbook

Digital twin systems for VET education

YEAR:
2026

REALISED BY:
Learnable (IT)
Digital Smart srl (IT)
ETN Training Vision Ireland (IE),
University of Malaga (ES)
Málaga TechPark (ES)
Innovation Frontiers IKE (GR)
University of the National Education
Commission, Krakow (PL)

Co-funded by
the European Union

DiTwin – Digital Twin for VET school

DiTwin Handbook

The editing of this document was finished on January 2026.

Project website: https://www.ditwin.eu/

DiTwin is a Cooperation Partnership project in vocational education and training sector (KA220-VET) funded under the Erasmus+ Programme.

Project Number: 2023-1-IT01-KA220-VET-000154611

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Agenzia nazionale Erasmus+ INAPP. Neither the European Union nor the granting authority can be held responsible for them.

This document has been created by the collaboration of the whole DiTwin partnership: Learnable Società Coooperativa a r.l. (IT) -project Coordinator, Digital Smart srl (IT), ETN Training Vision Ireland (IR), University of Malaga (ES). Málaga TechPark (ES), Innovation Frontiers IKE (GR), University of the National Education Commission, Krakow (PL).

Contents

Introduction

Embracing the Future with Digital Twins in Vocational Education and Training

In an era marked by rapid technological advancement and digital transformation, the ability to adapt educational models to the evolving needs of industry has become essential. Digital Twin (DT) technology—once limited to high-end engineering or manufacturing contexts—is now gaining significant traction in the field of Vocational Education and Training (VET). This manual has been created to serve as a comprehensive and practical guide for educators, trainers, and school leaders who want to understand and implement Digital Twin-based learning in their institutions.

A Digital Twin is a virtual representation of a real-world object, process, or system that enables real-time monitoring, analysis, and simulation. It connects data from the physical world to its digital counterpart through sensors, models, and interfaces, offering new ways to understand and optimize operations. For educators and VET providers, this technology presents a unique opportunity to offer students realistic, interactive, and risk-free learning experiences that mirror modern industrial environments.

The manual begins by laying the foundations: defining what Digital Twins are, how they work, and what components and technologies they include. It then explores their relevance in vocational education, particularly in closing the gap between school-based learning and real-world industrial practices. As we delve into pedagogical strategies and curriculum development, readers will discover how to engage students through hands-on tasks, digital simulations, teamwork, and interdisciplinary learning.

Drawing on contributions from project partners across Europe, this manual also presents real case studies and examples of successful collaborations between VET institutions and Industry 4.0 companies. These stories illustrate the value of co-designed training programs and shared digital infrastructures. Finally, we look ahead to future trends, career opportunities, and the continuous learning pathways that will enable students and teachers to stay up to date in a fast-changing digital landscape.

This guide is designed not only to inform but to inspire. By embracing Digital Twin technology, VET systems can become more agile, more connected to industry, and better prepared to equip learners with the skills they need for the jobs of tomorrow.

1. Introduction to Digital Twin Technology

1.1 Industry 4.0 and Digital Twins

The Industrial Revolution, which emerged in 18th-century England, decisively transformed an economy based on artisanal labour into one based on mechanised production. The introduction of James Watt's steam engine, alongside innovations such as Richard Arkwright's water-powered spinning machine, increased productive capacity and established coal as a primary energy source. This change not only increased efficiency and the volume of manufactured goods but also redefined the human-technology relationship by demonstrating that mechanical power could far exceed muscular force. Today, this period is regarded as the First Industrial Revolution.

Electricity was already being used as a source of energy in industry in the late 19th and early 20th centuries. This change made it possible to reorganise production facilities - replacing the large mechanical shafts with individual motors - which increased flexibility, safety, and lighting in the workshops. On the other hand, with the mass production model, a paradigm set in motion by Henry Ford for his Model T car, large-scale manufacturing was addressed. This prompted the adoption of new organizational models, such as scientific work management and the assembly line, which introduced a strict division of tasks and the standardisation of components. These advances drastically reduced production times and unit costs, making previously exclusive goods accessible to the broader population. In this way, the Second Industrial Revolution took place.

The next significant development occurred in the 1960s and 1970s. In the post–World War II era, computers, electronic control, and automation technologies were consolidated, leading to the emergence of industrial robotics. The introduction of computer numerical control (CNC) and programmable logic controllers (PLC), as well as the first industrial robots — most notably the 'Unimate', which was installed in a General Motors plant in 1961 — transformed production lines from rigid, single-product systems into flexible setups built around robotic cells.

Thus, by simply reprogramming the software and standardising tooling and sensors, a single production line could manufacture several product variants or incorporate design modifications in just a few days.

This new paradigm, known as the “Third Industrial Revolution,” introduced the concept of flexible manufacturing systems (FMS), laid the foundations of computer-aided design and computer-aided manufacturing (CAD/CAM) and promoted lean production strategies such as just-in-time, decisively expanding the industry's ability to respond to ever-changing markets.

We are currently witnessing the so-called 'Fourth Industrial Revolution' — or 'Industry 4.0' — while some experts are already outlining the features of an imminent 'Fifth Industrial Revolution', which will be characterised by human-machine collaboration and sustainability as its guiding principle. This stage is distinguished by the comprehensive digitalization of the entire value chain, from conceptual design and engineering to production, logistics and after-sales customer interaction. It is important to note that all these processes are interconnected and orchestrated by a single data management system.

This convergence has been made possible by technologies such as cloud computing, artificial intelligence, the industrial internet of things (IIoT), collaborative robotics, and additive manufacturing.

Alongside these technologies, the 'digital twin' — a virtual replica of physical elements, machines, robots, production lines or even entire factories — is also emerging. Fed by real-time data, it allows scenarios to be simulated, performance to be optimised, and failures to be predicted before they materialise. With this, industry not only gains in flexibility and efficiency, but also closes the information loop between the physical and digital worlds, laying the foundation for a resilient, customized, and fully sustainable model of manufacturing.

1.2 Key Components of a Digital Twin

As previously discussed, a digital twin is a virtual representation of a physical system, capable of replicating its behaviour and delivering real-time data that reflects its current state. These virtual outputs are continuously compared with data from the real-world counterpart, allowing the system —through statistical methods or artificial intelligence — to predict future performance, detect faults, and support preventive maintenance strategies. To fulfill these functions, the typical architecture of a digital twin is illustrated in Figure 1.

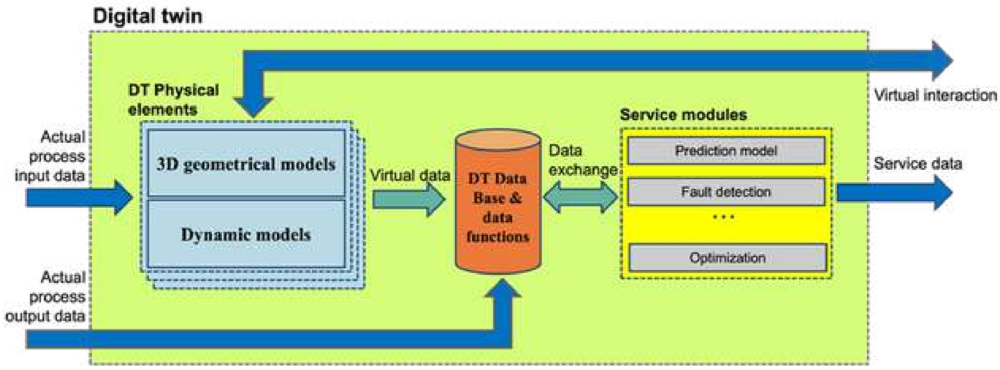


Figure 1. Architecture of a digital twin

On the left side of the diagram, the virtual representation of the physical system (DT Physical elements) is depicted. This consists of a set of 3D geometric models, responsible for capturing the system's morphology, and dynamic models that simulate its operational behaviour. These models receive the same input data as the real system and, when executed, generate virtual output data that is routed to the digital twin's data platform (DT Database). There, the virtual data are integrated with real-time measurements from the physical process—indicated by the blue input arrow—becoming accessible for bidirectional interaction with various service modules (such as prediction, fault detection, and optimization). These modules process and refine the data, producing service data to inform both tactical and strategic decisions. Additionally, the digital twin can interoperate with other twins through the virtual interaction layer at the top, allowing for the cooperative simulation of large-scale and complex systems.

Consider, for instance, the development of a digital twin for a robotic arm. This involves integrating detailed 3D models of each link—from the base to the gripper—alongside the dynamic equations that govern its motion. A single trajectory command is synchronously transmitted to both the physical robot and its virtual twin. The latter runs the simulation and generates virtual data on gripper position, motor torques, electrical currents, and other relevant state variables. These data are logged in the digital twin's database, together with their real-world counterparts from the physical system.

The service modules perform comparative analyses, enabling key functions such as early anomaly detection, predictive maintenance planning, and control strategy optimization—along with any additional services specific to the application.

1.3 The Digital Twin and Its Applications

The digital twin has become a key tool for cost reduction in industry because of its dual function. On the one hand, it acts as a virtual test bed: it allows complete production lines - including material flows, process parameters, and energy consumption - to be 'modelled and simulated', so that design errors are detected and corrected before investing in the physical infrastructure. On the other hand, when connected in real time to its physical counterpart within a 'cyber-physical system', the digital twin proves invaluable for early fault detection, production process optimization, and predictive maintenance based on artificial intelligence. As a result, downtime is minimized, product quality is enhanced, and machine lifespan is extended. Moreover, historical data feeds continuous improvement algorithms, operator training in augmented reality environments, and enables carbon footprint assessment throughout the product lifecycle.

The success of digital twins in the manufacturing industry has led to their use spreading to areas for which they were not originally intended. A prime example is precision agriculture, where digital twins of soils, crops and infrastructure enable detailed modelling of the evolution of plots of land — whether in open fields or high-tech greenhouses— and allow for highly accurate anticipation of needs. By integrating real-time data from moisture sensors, weather stations, hyperspectral cameras, and mobile inspection robots, these twins can predict growth rates, water stress, or phytosanitary risks.

As a result, resources such as water, fertilizers, and crop protection agents are applied precisely where and when needed, reducing costs and minimizing environmental impact. Furthermore, by simulating climate and market scenarios, digital twins support sowing decisions, enhance post-harvest logistics, and allow for yield forecasting weeks in advance. This data-driven approach is transforming agriculture into an intelligent cyber-physical ecosystem, where each hectare has its virtual avatar to guide decision-making and optimize both productivity and sustainability. Thus, the concept of Agriculture 4.0 has also emerged.

The tourism sector has also adopted digital twin technology for the virtual reproduction of real environments, paving the way for 'Tourism 4.0'. Using drones equipped with LiDAR sensors and high-resolution cameras, structures and archaeological sites—such as the basilicas and forums of ancient Rome—can be accurately reconstructed into detailed 3D models.

These models not only preserve cultural heritage but also allow for virtual exploration without the limitations of physical terrain or the degradation caused by mass tourism. Furthermore, these digital twins are employed in augmented reality applications, overlaying historical graphics or multimedia guides onto real monuments and landscapes, while providing visitors with a real-time contextual narration that enriches the cultural experience. For an even more immersive experience, these models can be deployed on metaverse environments where future travellers can walk through virtual replicas, interact with objects and avatars, plan personalised routes and assess accessibility before making travel decisions. This has two consequences: firstly, it diversifies the tourism offer by providing hybrid physical-digital experiences; and secondly, it generates valuable data on visitor flows and usage patterns to support better capacity planning, heritage preservation, and destination sustainability.

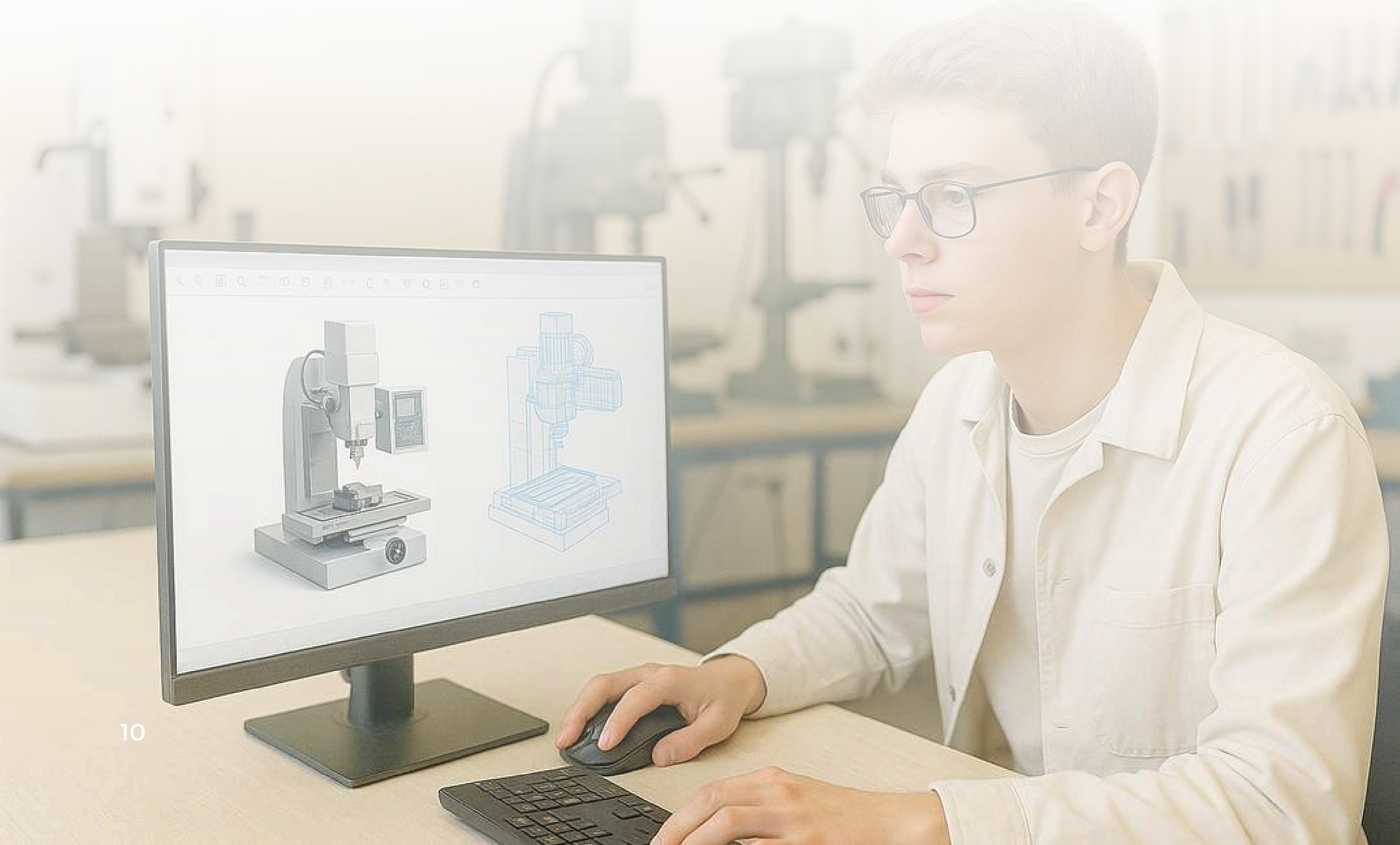
In the healthcare domain, the concept of 'Medicine 4.0' has emerged thanks to the incorporation of digital twins. The earliest adopters of this technology were orthopaedic surgery and neurosurgery, where surgical navigation systems incorporate detailed 3D replicas of the patient, allowing surgeons to simulate procedures in advance. In orthopaedics, for example, the affected bone is meticulously reconstructed, enabling the surgeon to virtually plan milling and drilling paths to ensure an exact fit for the prosthesis. In neurosurgery, a 3D model of the patient's brain helps to determine the best approach for accessing the lesion while minimising damage to critical structures. In addition to these pioneering techniques, digital twins are also being used to plan resections with accurate safety margins and predict haemodynamic response in real time during vascular procedures, such as aortic aneurysm repair, and oncological procedures, such as liver or kidney tumour resection.

Beyond the operating theatre, pharmacology is using data-driven digital twins to predict the pharmacokinetics and side effects of drugs in specific patient groups. These twins rely on statistical models trained with clinical histories, genomic data, and biomarkers that allow to categorise patients and adjust doses in a personalised way. Meanwhile, multi-scale digital twins — combining molecular dynamics, organ-level physiology, and data from wearable devices — are being developed to predict epileptic seizures, arrhythmias and metabolic decompensations before they occur. The result is a cyber-physical ecosystem in which the operating theatre, the laboratory and the patient are interconnected, enabling anticipatory, minimally invasive, person-centred medicine.

Co-funded by the European Union

1.4 Digital Twins in Education

Higher education institutions have exploited the potential of digital twins by integrating them as active, contextualised learning tools. A virtual replica of a machine, pilot plant, or even a complete laboratory enables students to trial procedures in a risk-free environment, eliminating the operational risks and costs associated with physical equipment. Within problem-based learning frameworks, students can diagnose faults, adjust parameters, and immediately observe the repercussions of their decisions. This approach helps to close the theory-practice cycle, providing a deeper and more motivated learning experience.
This approach has proven effective in both chemical engineering degrees, where the combination of computer simulation and gamification elements enhances online training, and in training aeronautical maintenance personnel using digital turbojet engine twins. Similarly, virtual laparoscopic surgery simulators allow future specialists to hone their psychomotor and strategic skills without compromising patient safety, while digital replicas of smart electrical grids facilitate operator training in critical scenario management. In conclusion, digital twins create a flexible, accessible and scalable educational ecosystem that can promote academic excellence and the development of professional skills in a rigorous and sustainable way.



2. The Relevance of Digital Twins in VET

2.1 Why it matters: the potential impact of Digital Twin on Industry 4.0 and the future workforce

2.1.1 In Industry 4.0: a driver for efficiency and innovation

Process Optimization

Digital twins enable real-time monitoring of plants, machinery, and entire production systems. This capability brings several concrete benefits. Firstly, it supports predictive maintenance, helping to reduce machine failures and minimize downtime. Secondly, through advanced simulations, it becomes possible to test modifications or new products without incurring real-world risks. Additionally, digital twins contribute to cost reduction: according to a study (Oliver Wyman (2016), Digital Twins: Identical, But Different, Insight report,) their use can shorten design and development timelines by up to 25%, leading to savings of 10–15% in overall costs.

Integration with Other Technologies

Digital twins are highly versatile and can be integrated with various cutting-edge technologies. When combined with the Internet of Things (IoT), they enable real-time data collection from physical systems. Through integration with Artificial Intelligence (AI), they support predictive analytics and automated decision-making processes. In conjunction with Big Data, they allow for the management and interpretation of large volumes of complex information. Furthermore, integration with SCADA (Supervisory Control and Data Acquisition) server systems helps bridge the gap between the data gathered from the physical environment and its digital representation.

Collaboration and Transparency

Digital twins offer a shared, constantly updated view of the entire lifecycle of a product or process. This visibility enhances collaboration across different teams and departments and facilitates more efficient communication between suppliers, manufacturers, and customers. As a result, workflows become more transparent, coordinated, and aligned with real-time conditions.

2.1.2 For the future workforce: skills and employability

New Skills Required

The integration of digital twins into industrial environments is reshaping the skill sets required from professionals. Today's workers must be able to read and interpret digital data, such as dashboards, graphs, and key performance indicators (KPIs). They also need to understand information coming from sensors and monitoring systems, as well as interpret simulations and predictive scenarios. For example, a production line operator should be able to analyze engine vibration and temperature data to recognize when maintenance is needed.

In addition to data literacy, professionals must know how to interact with digital interfaces and virtual environments. This includes using HMIs (Human-Machine Interfaces), navigating 3D digital twins of plants or systems, and being comfortable with augmented and virtual reality (AR/VR) tools. A practical example would be a maintenance technician who explores a virtual replica of a facility to plan an intervention without physically accessing the site.

Digital troubleshooting is another crucial competency. Workers must be capable of identifying anomalies or faults through digital tools, running simulations to diagnose issues, and collaborating with technical teams to find and implement effective solutions. For instance, a maintainer might simulate a component replacement within the digital twin to assess the outcome before taking any physical action.

A deeper understanding of digitised industrial processes is also essential. This involves familiarity with automated workflows, the ability to follow software-driven procedures, and the flexibility to operate within interconnected production systems. A logistics operator, for example, should be aware of how modifications in a warehouse's digital twin affect inventory levels and stock management.

Lastly, effective digital collaboration and technical communication are key. Professionals are expected to share data and reports across departments via digital platforms, communicate efficiently with engineers, analysts, and developers, and participate in decision-making processes based on data insights. For instance, a production team might use the digital twin to coordinate adjustments and ensure all stakeholders are aligned.

Immersive and Practical Training

Digital twins also offer a powerful resource for education and training. They create realistic, interactive, and risk-free learning environments where students can engage with virtual systems and explore complex scenarios safely. This hands-on approach helps them develop not only technical skills, but also transversal competencies such as problem-solving, critical thinking, and digital collaboration—skills that are essential in modern industrial contexts.

Employability and Adaptability

Training with digital twins significantly enhances students' employability. It prepares them to work in highly automated and technologically advanced environments, while also equipping them to take on emerging roles in fields such as intelligent maintenance, digital design, and industrial data management. Their ability to adapt to fast-evolving workplaces becomes a valuable asset in the context of Industry 4.0.

2.2 Impact on VET Programs, how Digital Twins can influence technical training

Transformation of Traditional Teaching

The integration of Digital Twins into Vocational Education and Training (VET) represents a major shift from traditional, theory-based instruction to a more experiential, immersive, and interactive form of learning. Instead of passively receiving information, students actively engage in simulations that replicate real industrial scenarios. They can interact with virtual representations of plants, machinery, or production processes, and explore complex situations in a safe environment. This hands-on approach not only enhances motivation and engagement but also fosters greater responsibility for learning outcomes. Additionally, it supports peer-to-peer collaboration and enables more dynamic forms of evaluation.

Customized Training Paths

One of the key advantages of Digital Twins is their flexibility, which allows for highly personalized learning experiences. Training content can be tailored to match the student's current skill level, while also accommodating different professional goals. This makes it possible to offer differentiated learning pathways and to integrate interdisciplinary modules, fostering a more targeted and relevant educational journey for each learner.

Development of Operational and Digital Skills

Through the use of Digital Twins, students acquire a wide range of both operational and digital skills. They learn how to read and interpret data from digital systems, operate HMI (Human-Machine Interface) panels, navigate 3D environments, and collaborate in digital teams. Decision-making becomes a key competence as students use simulations to test various approaches and strategies. These experiences prepare them for modern, highly automated workplaces where interaction with cyber-physical systems is routine. At the same time, they develop essential soft skills such as problem-solving, critical thinking, and effective communication, along with familiarity with virtualized work settings.

Contextual Learning

Digital Twins offer contextualized learning opportunities by allowing students to engage with virtual environments that closely mirror real-world industrial systems. This enables learners to grasp how complex machinery and processes work in practice. They can observe the immediate effects of modifications or errors and gain a broader, systemic understanding of how production flows are interconnected. For example, a mechatronics student might program a robotic arm and watch it interact with a virtual assembly line, gaining valuable insights without any physical risk.

Development of Operational and Procedural Skills

The use of Digital Twins also enhances the development of specific technical and procedural skills. Students can practice diagnostic and predictive maintenance by analyzing sensor data and running simulations. They learn how to control processes by adjusting parameters in a virtual environment, and they gain hands-on experience in managing safety by responding to simulated emergency scenarios. This kind of risk-free practice helps solidify competencies before entering a real-world setting. For instance, learners can simulate equipment malfunctions and plan maintenance interventions in a fully virtual space.

Integrated Digital Skills

In addition to technical expertise, Digital Twins help students build cross-cutting digital skills that are applicable across sectors. These include navigating 3D and HMI interfaces, interpreting technical data, and using modeling and simulation software. In practical applications such as precision farming, for example, students might use digital dashboards to monitor and manage irrigation and fertilization processes, thereby learning to apply digital tools to real-world challenges.

Adaptive and Personalised Training

Digital Twins support adaptive learning by allowing educational content and activities to be adjusted in real time. This adaptability ensures that each student follows a pathway aligned with their current competencies, career aspirations, and the technical demands of their specific vocational area. A beginner can start with guided, step-by-step exercises, while more advanced students can engage with complex, open-ended scenarios that challenge their problem-solving and decision-making skills.

Real Skills Assessment

Another strength of Digital Twin technology is its ability to facilitate realistic and data-driven assessment. Educators can track student actions and results within the simulation, providing an objective basis for evaluating technical skills. Assessments can be formative, offering immediate feedback to guide improvement, and authentic, as they take place in environments that closely mimic real-world conditions. For example, a teacher might evaluate a student's ability to troubleshoot a simulated technical problem in a virtual facility, gaining clear insights into their readiness for workplace tasks.

2.3 Bridging the Skills Gap: how Digital Twin technology can improve employability.

Connecting Education and Industry

One of the most pressing challenges in technical and vocational education is the persistent gap between the skills demanded by industry and those actually acquired by students during their training. Digital Twins offer a powerful way to bridge this divide. By faithfully replicating real industrial environments, machinery, and processes, they bring the workplace directly into the classroom. This allows students to engage with realistic scenarios in a virtual setting, gaining practical experience even when access to complex or costly physical equipment is limited. As a result, training becomes more aligned with current industry practices and technologies.

Development of Advanced Technical Skills

Through Digital Twins, students have the opportunity to develop high-level technical skills that are increasingly relevant in modern industry. They become familiar with digital tools and human-machine interfaces (HMI), and learn how to read and interpret data from sensors and Internet of Things (IoT) systems. In addition, they gain operational experience by working on virtual installations that simulate real tasks—such as performing maintenance, executing quality control procedures, or managing logistics workflows—helping them build competence and confidence before entering the job market.

Problem-Based Learning

Digital Twins also support a problem-based learning approach, where students are actively involved in solving real-world challenges. Training can be structured around tasks such as diagnosing failures, optimizing production processes, or making operational decisions in response to simulated events. Critical scenarios—like system breakdowns, emergency situations, or shifts in production demand—can be simulated to test students' response and reasoning. This methodology encourages interdisciplinary collaboration, connecting knowledge from mechanics, electronics, IT, and logistics, and better reflecting the integrated nature of today's industrial environments.

Alignment with Business Requirements

As companies increasingly adopt Industry 4.0 technologies, they seek professionals who can understand and interact with complex digital systems, quickly adapt to new tools and workflows, and operate effectively in collaborative, often virtual environments. Digital Twin-based training helps meet these expectations by equipping students with the technological fluency and flexibility required in the modern workplace. In this way, education becomes more responsive to the real needs of employers, enhancing students' employability and reducing the time needed for on-the-job training.

2.4 Strategies to develop synergies between VET system and Industry 4.0

The overarching goal is to build a robust industrial-training ecosystem that can effectively respond to the challenges of digital transformation while preparing a workforce equipped with the necessary skills for the future. This involves rethinking the relationship between education and industry, and fostering closer collaboration through shared resources, co-designed learning paths, and innovative training environments.

Co-Design of Training Courses

One of the most impactful strategies for aligning education with the needs of the job market is the co-design of curricula between schools and companies. This collaborative approach ensures that training content reflects current industry demands and technological advancements. It allows for the integration of modules focused on emerging technologies—such as Digital Twins, IoT, and Artificial Intelligence—and encourages the active involvement of business professionals in the teaching process. Their expertise brings real-world perspectives into the classroom, enriching the learning experience.

Laboratories and Simulated Environments

Creating technology labs that are accessible to both schools and companies represents another key step in strengthening the connection between training and industry. These shared spaces allow students to interact with advanced technologies—including Digital Twins, robotics, and augmented reality—and gain hands-on experience in simulated environments that closely resemble real-world production settings. Such exposure not only enhances technical competence but also builds confidence in navigating digitized workspaces.

Internships, Traineeships and Dual Apprenticeships

Work-based learning opportunities play a central role in professional development. Programs such as internships, traineeships, and dual apprenticeships provide students with direct access to the workplace, where they can apply their skills in practical contexts and learn from experienced professionals. These experiences are also critical for developing essential soft skills such as autonomy, communication, and adaptability. In addition, problem-solving projects assigned during placements help students strengthen their critical thinking and decision-making abilities in real-world scenarios.

Local Networks and Strategic Partnerships

To enhance their capacity for innovation and responsiveness, schools are increasingly joining local networks and forming strategic partnerships with other educational institutions, companies, and public bodies. These collaborations facilitate the sharing of resources, experiences, and best practices. They also establish a structured dialogue with the local business community, enabling schools to stay attuned to evolving industry needs. Furthermore, participation in national and European funding programmes—such as Erasmus+, PNRR, or Digital Europe—can support the development of joint initiatives and the scaling up of successful models.

Digital Platforms for Collaboration

Digital platforms serve as powerful tools to coordinate and manage training projects that involve multiple stakeholders. They allow schools and companies to collaborate more efficiently, track student progress and skill acquisition, and match learners with relevant job opportunities. Examples include online portals for managing traineeships, platforms for organizing and monitoring Digital Twin activities, and virtual environments for delivering remote learning. These technologies contribute to a more integrated and dynamic learning ecosystem, where education and industry work together to shape the workforce of tomorrow.

3. Pedagogical Strategies for Teaching with Digital Twins

Digital Twins are real-time, virtual representations of physical systems, offering immersive, interactive, and data-driven experiences that can transform teaching and learning. Here, we would like to present some effective pedagogical strategies for integrating digital twins in vet education across various contexts.

We would like to list them below:

- Experiential Learning (when we use Digital Twins for hands-on simulation-based experiences. Students can interact with the twin of a physical system to explore cause-and-effect relationships and practice problem-solving in real time. The Pedagogical Basis here is Kolb's Experiential Learning Cycle (Concrete Experience → Reflective Observation → Abstract Conceptualization → Active Experimentation).

- Inquiry-Based Learning (we lead frame lessons around open-ended questions and problems that students investigate using the digital twin. For example, students could investigate how changes are implemented in a digital twin of an HVAC system. What we do here is promote scientific reasoning, critical thinking, and deep understanding.

- Project-Based Learning (PBL) (we ask students to design, to do tests, and iterate solutions using digital twins in long-term, collaborative projects. Vet students might develop and optimize some processes using a digital twin of a district. We can use collaborative platforms and version control for iterative development. Problem-Based Learning (here we could present real-world problems modeled in the digital twin environment. We could use a digital twin of a veterinary treatment facility to address contamination issues. In this case, we could encourage the application of interdisciplinary knowledge in authentic contexts.

- Scaffolding and Adaptive Learning (here we could gradually introduce complexity using DTs with built-in analytics or real-time feedback. We can begin with basic functionality, then add data layers (e.g., IoT, predictive analytics) as learners advance.

- Reflective Learning (here in this method, we could encourage students to reflect on their actions within the DiTwin, analyzing what worked, what didn't, and why. What could help is maintaining learning journals or using structured reflection prompts after simulations.

- Collaborative Learning (We could use DiTwin in group settings to enhance communication, negotiation, and shared problem-solving. In a virtual factory digital twin, students can take on different roles (e.g., operator, engineer, manager) to tackle production challenges.

- Gamification and Motivation (we could add game-like elements such as challenges, badges, and leaderboards within the DT environment. Reward efficient system designs or innovative solutions using real-world data metrics. We need to ensure game mechanics support learning goals rather than distract from them.ù

- Flipped Classroom Integration (we could assign DiTwin interactions as pre-class or post-class work to maximize in-class discussion and analysis. Students explore a DiTwin of an energy grid during lessons, then debate sustainability strategies in class, during workshops.

- Assessment and Feedback (we could use data from DiTwin interactions to assess learning outcomes in real time. We could have two types of Assessment:
  - Formative: Track user decisions and provide real-time feedback.
  - Summative: Evaluate final system performance or learner generated reports.

Also, here in DiTwin we could find hands-on tasks where students create and interact with digital twins, organized by skill level and discipline. These tasks promote deep learning, problem-solving, and digital literacy by placing students in active roles as designers, analysts, or operators of digital systems.

The main objective here is to understand the concept of a digital twin and basic interaction with one. What is also important is to begin designing or partially building a digital twin, and engage in analysis and iterative improvement. So here we could have such tasks as:

- Explore a Pre-Built Digital Twin,
- Modify Parameters in a Twin
- Create a Digital Twin of a Simple Physical Object
- Simulate and Optimize a Physical System
- Build a Digital Twin of a Smart Room or Lab
- Design a Predictive Maintenance System

We would also like to draw attention to Cross-Task Enhancements:

- Reflection Journals: Students document what they observed, changed, and learned from their digital twin interactions.
- Peer Reviews: Teams evaluate each other's twin models for realism, usability, and effectiveness.
- Mini-Hackathons: Timed challenges where students must solve problems using or modifying their twins.

Using digital twins to test processes in virtual environments before real-world applications is one of the most powerful and practical uses of this technology, especially in education, engineering, business, and systems design. Here's a breakdown of how and why it's effective, and how it can be implemented in educational or training settings.

Testing processes in a digital twin means simulating workflows, systems, or behaviors in a digital environment that mirrors real-world conditions, before deploying or implementing them physically.

- It allows for safe trial-and-error, optimization, and forecasting outcomes.
- Common in engineering, manufacturing, healthcare, urban planning, and logistics.

Providing online materials, such as videos, simulations, and interactive modules, before practical sessions in a digital twin environment is a highly effective flipped classroom strategy. It prepares students cognitively, so they can engage more deeply during the hands-on phase with the digital twin.

Why Use Pre-Class Materials with Digital Twins?

Benefit	Impact
Better Preparedness	Students arrive with baseline understanding, ready to apply concepts.
Maximized Hands-On Time	Less time spent explaining, more time spent experimenting.
Supports Diverse Learning Styles	Visual (videos), kinesthetic (simulations), and auditory (narration) learners all benefit.
Improved Learning Outcomes	Reinforces knowledge through pre-study and active practice.

Recommended Online Materials Before digital twin-based activities:

A) Concept Introduction Videos

- What: Short (5–10 min) explainers of key concepts and processes related to the DT topic.
- Example Topics:

  - How a digital twin works
  - Sensor data flow and interpretation
  - Overview of the system being modeled (e.g., HVAC, wind turbine)

B) Guided Simulation Walkthroughs

- What: Interactive modules or screencasts showing how to navigate the DiTwin interface, adjust variables, and analyze outcomes.

- Tools to Use:
  - LMS Integration (e.g., Moodle, Canvas): Embed simulations with quizzes.
  - H5P: Interactive video quizzes or branching scenarios.

C) Pre-Lab Assignments

- What: Low-stakes quizzes or worksheets that ensure students:
  - Know what the DiTwin simulates
  - Understand key variables and controls
  - Can interpret simple output metrics

- Goal: Activate prior knowledge and check understanding.

D) Annotated System Models or Dashboards

- What: Provide screenshots or interactive previews of the DT system with explanations.

- Purpose: Familiarize students with components and their roles before hands-on testing.

E) Real-World Case Study Videos

- What: Short videos showing how similar digital twins are used in industry (e.g., smart grids, aircraft maintenance).

- Result: Increases relevance and motivation.

Encouraging teamwork in solving real-world industry problems using digital twins fosters collaboration, critical thinking, and real-world readiness. Digital twins provide an ideal platform for this because they mirror complex systems, exactly the kind of problems teams encounter in industry.

Why Use Teamwork in Digital Twin-Based Learning?

Benefit	Impact
Simulates industry conditions	Most real-world DiTwin projects involve multidisciplinary teams.
Fosters communication & collaboration	Teams must coordinate decisions, tasks, and interpretations of data.
Enhances problem-solving	Different perspectives lead to more innovative and viable solutions.
Builds soft skills	Leadership, negotiation, responsibility-sharing—all critical in the workplace.

4. Setting Up Digital Twin-Based Activities in Class: the DiTwin Modules - step by step guide

4.1 How the system works

The system developed by the DiTwin partnership enables hands-on and work-based learning (WBL) activities at a distance by providing a 3D simulation of a real object connected to the system. This opens up multiple possibilities, such as simply observing how a machine operates in real life or interacting with the connected machinery through the simulation and receiving direct feedback from it. The DiTwin system is based on 3 main laboratories:

Remote Laboratory for Additive Manufacturing: This laboratory integrates a network-connected 3D printer with the DiTwin Platform to support additive manufacturing and computer-aided design (CAD) activities. It allows users to conduct virtual simulations of 3D printing processes. Through the system, users can send generated code directly to the 3D printer and monitor the additive manufacturing process in real time via a webcam.

Remote Robotic Cell Laboratory: This laboratory features a robotic cell built around a cobot-type robotic arm, equipped with proximity sensors and a conveyor belt. All components are managed through the robotic arm's control unit. A digital twin of this robotic cell replicates all its functionalities, enabling students to program tasks in the digital twin environment. These tasks can then be sent to the physical robotic cell, with the execution monitored in real time through a webcam.

Remote Laboratory for Managing Production Processes in an Industry 4.0 Environment: This laboratory is a Cyber-Physical Factory, designed to mirror the new production paradigm of Industry 4.0. It offers a modular Smart Factory system for both teaching and research, capable of reproducing various setups of automated systems used in Industry 4.0.

The DiTwin System can be used by schools and students without the need to install any particular software. Although some common software can be required (i.e., remote desktop apps and video conference apps) the users can connect through the platform and directly book the lessons created.

4.2 The modules

Users can choose between three modules, with different lessons for each module.

The modules actually produced cover the following 3 profiles of the DiTwin Competence Framework:

- Profile 1. Additive Manufacturing technician
- Profile 4. Automation technician for Industry 4.0
- Profile 10. Robot machines technician for Industry 4.0

Profile 1. Additive Manufacturing technician

An Additive Manufacturing Technician is responsible for the smooth operation of 3D printing machines, including setup, maintenance, and repairs of equipment. They understand the fundamentals of additive manufacturing, the functioning of different systems, and the benefits of each technology. Key tasks include preparing and managing print files, ensuring adherence to quality standards, diagnosing and performing maintenance, and selecting appropriate printing materials for specific applications. They ensure quality control throughout the process, from preparing the system to operating basic tasks on the 3D printer.

Profile 4. Automation technician for Industry 4.0

An Automation Technician for Industry 4.0 is responsible for creating, repairing, and maintaining basic automated systems in industrial settings. They have a solid understanding of mechatronics, automation, robotics, electrical engineering, electronics, pneumatics, and hydraulics. Their role includes operating Programmable Logic Controllers (PLCs), monitoring automated production systems, performing basic repairs and maintenance, and installing automated systems. They are also skilled in describing maintenance indicators and diagnostic techniques to ensure the smooth operation of automated processes.

Profile 10. Robot machines technician for Industry 4.0

The Robot Machines Technician for Industry 4.0 is responsible for setting up, operating, and maintaining robotic machines in industrial settings. They have knowledge of robot components, characteristics, and applications, and can distinguish between advanced and collaborative robots, including their types and the differences from traditional industrial robots. They can program, set up, and monitor industrial robotic arms, perform basic maintenance, and identify risks and safety issues during robot operation. They also understand maintenance indicators and diagnostic techniques to ensure optimal robot performance. The modules developed align with the profiles required by Industry 4.0 in partner countries, including Italy, Spain, Ireland, Greece, and Poland.

The DiTwin modules are built on Digital Twin technology and replicate various technical systems or machinery associated with the previously described profiles. These modules focus on specific learning outcomes tied to practical and experiential learning, while broader, profile-related learning outcomes are achieved through the standard curriculum.

In many cases, the theoretical or general concepts taught during standard lessons serve as prerequisites for engaging with the DiTwin modules. These modules, which offer hands-on experiences with the machinery relevant to different profiles, can serve as the culmination of the learning path, allowing students to apply the knowledge they have acquired.

However, this does not mean that the modules are limited to practical application alone. The digital twin systems also facilitate observations and activities that help develop and reinforce both theoretical and foundational knowledge related to the selected profiles.

4.3 Steps to use the DiTwin system

The system is intended to be used by users with the supervision of an expert teacher in order to avoid any damage to the labs due to improper use of equipment. The system can be used following the next steps:

1. The first step consists of accessing the DiTwin Platform (www.ditwin.eu/ditwin-platform-2/) available on the DiTwin website (www.ditwin.eu). The access is free and open.

2. On the DiTwin Platform, the user will choose one of the available modules. By clicking the button “go to the module” you will find a short description of the module and the lesson plans prepared. The teachers will understand the implementable training activities, evaluating to what extent they can adapt to their learning objectives and curricula.

3. At the end of the Module page, you can find a reservation form. The teacher should fill in the required fields and indicate the specific lesson and period they would like to have the training session. With the submission, the message will be sent to a specific lab that provides training on the module selected and a automatic confirmation email will be sent to the user.

4. After that, the staff of the lab sends an email in order to plan the activity and define the precise date. During this step, the teachers will be informed about the needed communication tools to be guided by the staff and connect with the Di Twin system. The project uses free tools for this purpose.

5. At this point, the responsible staff have set up the physical lab with the needed materials and you can attend the session.

In order to have a comprehensive overview of the entire process, you can use the video tutorial developed and published by the DiTwin partnership on the DiTwin website at www.ditwin.eu

4.4 Strategies and policies to integrate Digital Twin-based activities at school

To implement Digital Twin-based activities effectively, vocational schools should follow a multi-dimensional strategy composed of the following pillars:

Integration into existing curricula

In order to integrate digital-twin based activities into VET curricula it is necessary to start from the learning outcomes.
The first step is to identify the potential learning outcomes (competencies, knowledge and skills) provided by a digital twin system. Every digital twin allows users to achieve specific learning outcomes linked to the machinery simulated.

Once you have an overview of the potential learning outcomes achievable, you need to map them against the different school subjects and curricula. In this way, you will be able to understand what subjects could potentially take advantage of the digital twin and what can be the learning outcomes involved.

Now you can plan a digital twin-based project for one or more subjects that can separately evaluate the achievement of specific learning outcomes.

Educational methodologies

The added value of digital twin technology is the capacity to develop experiential learning activities without having the real machinery at school. Considering that experiential learning is at the basis of the educational activities implementable within the domain of digital twin. An effective pedagogical approach to adopt is project-based learning (PBL). In this model, students work on real or simulated projects where they design, test, and optimize digital replicas of real-world systems. This not only enhances technical knowledge but also cultivates problem-solving, creativity, and teamwork.

Furthermore, innovating assessment methods is crucial. Traditional tests may not adequately capture the depth of student understanding in these dynamic fields. Instead, using digital twin platforms, students can be assessed through real-time simulations and practical tasks that mirror actual industrial scenarios.

Teacher Training and Professional Development
Teachers play a pivotal role in any educational innovation, and their continuous professional growth must be a top priority. Schools should provide digital upskilling programs that cover Digital Twin platforms, simulation software, and the broader ecosystem of Industry 4.0 technologies.

To sustain this growth, it is beneficial to foster collaborative networks where educators can share resources, co-develop digital twin-based scenarios, and learn from one another's experiences. These communities of practice help create a culture of innovation and mutual support.

Additionally, providing teachers with opportunities for industry placement, such as short internships or collaborative projects with companies using Digital Twin systems, allows them to gain first-hand knowledge and translate it into relevant and updated teaching strategies.

Institutional Governance and Leadership

The successful adoption of Digital Twin technologies also depends on forward-thinking governance. School leadership must embed DT integration into the institution's strategic planning, aligning it with broader goals for digital transformation and innovation.

This includes careful resource allocation—both in terms of budget and personnel. Dedicated funds and staffing are needed to maintain infrastructure, update tools, and support new teaching models.

Finally, managing this change requires strong internal leadership. Schools should designate digital champions or innovation coordinators who are responsible for guiding the implementation process, motivating staff, and ensuring that progress is tracked and evaluated over time.

5. Case Studies and Best Practices

This chapter presents concrete examples of how Digital Twin technologies are being successfully integrated into Vocational Education and Training (VET) across Europe. Drawing from partner countries and other European contexts, the case studies highlight innovative approaches to teaching and learning through immersive, data-driven simulations. Special attention is given to collaborative projects between VET institutions and Industry 4.0 stakeholders, where co-designed training paths and shared digital platforms have played a central role. These partnerships not only enhance the relevance of vocational training but also ensure that students acquire the practical and digital skills required by today's labour market. By exploring a variety of implementation models, this chapter aims to identify effective strategies, highlight transferable practices, and inspire further innovation in the use of Digital Twins for education and workforce development.

5.1 Digital twin in VET education

Digital Twin on Smart Manufacturing
Ongoing (2023–2026)

Comprehensive training program on Digital Twin technologies, including labs and practical tools for VET students in Bulgaria, Greece, Italy, Spain and Sweden.

Place: Europe

Type: EU funded

Link: https://digitaltwinproject.eu

Main Results:

- 450-hour course on Digital Twin technologies.
- Digital Twin Skills Index & Self-Evaluation Tool.
- Digital Twin labs for hands-on learning.

Digital Twins for Sustainability
Completed (2021–2023)

Initiative focused on using Digital Twin technology to promote sustainability, including case studies on wastewater treatment and 3D printing, in several European countries, including Ireland, Italy and Spain

Place: Europe

Type: EU-funded

Link: https://digital4sustainability.eu

Main Results:

- Short course on Digital Twin applications for sustainability.
- Multilingual online content for SMEs and learners.

Mediterranean Digital Twin Network for Climate Extremes
Ongoing (2023–2026)

The project MeDiTwin focuses on the creation of Digital Twin models for climate extremes in the Mediterranean region, promoting scientific exchange and summer schools.

Place: Europe

Type: EU funded

Link: https://meditwin-project.eu

Main Results:

- Development of climate models for the Mediterranean.
- Hosting summer schools and scientific exchanges.

Digital Twins: Building Your Own Virtual Lab
Ongoing (since 2022)

Project enabling students in the Basque Country to design and simulate control systems and factory automation using Digital Twin technology.

Place: Spain

Type: Public

Link: https://arrivet.org/index.php/arrivet/article/view/18

Main Results:

- Virtual commissioning for faster deployment times.
- Teacher training on virtual industrial systems

Biodiversity Digital Twin (BioDT) project
Ongoing (since 2022)

Project designed to address complex biodiversity dynamics through practical use cases, providing invaluable insights and tools for conservation and restoration efforts.

Place: Europe

Type: EU-funded

Link: https://biodt.eu/

Main Results:

- BioDT School
- Biodiversity Digital Twin prototype

Polish Digital Twin in Education Project
Ongoing (2023–2025)

Project aimed at creating Digital Twin training modules and integrating them into Polish VET curricula.

Place: Poland

Type: Public

Link: www.digitaleducation.pl

Main Results:

- Development of Digital Twin training modules.
- Integration of real-time simulations into education.

VET Simulator-Based
Ongoing (2024–2026)

The research project examines how upper secondary vocational education can prepare students for a future profession characterized by rapid technological development, sustainability requirements, and innovation.

Place: Sweden

Type: Public

Link: https://www.gu.se/en/research/simulator-based-teaching-and-learning-in-vocational-education

Main Results:

- Digital driving simulators
- Development of teaching methods in an industry shaped by demands for sustainability, innovation, and rapid technological development.

5.2 Industry Collaborations

Examples of Industry 4.0 and VET schools collaboration for the development of training paths co-develop Digital Twin projects.

The integration of Digital Twin (DT) technologies into vocational training represents a key frontier in aligning education with Industry 4.0 demands. Across Europe, VET institutions are starting to collaborate with industrial stakeholders to co-develop training paths that embed real-world DT applications into curricula. These collaborations help address skills mismatches, foster work-based learning, and ensure the relevance of vocational education in a rapidly digitalizing industrial landscape.

Siemens and the Didactic Initiative

Place: Germany

Project: **Siemens Technical Education Partnership with VET Centers**

Siemens AG has collaborated with several German vocational schools through its Siemens Technik Akademie to introduce Digital Twin technologies into technical training. The initiative combines virtual simulations with real-life production lines using Siemens' proprietary platforms (e.g., NX, Teamcenter).

Link: https://www.imove-germany.de/en/all_providers_from_a_z.htm?&p=/output/detail/pid/482

Outcomes:

- Learners simulate the lifecycle of a machine before engaging with physical components.
- Integration of DT into mechatronics and automation technician training.
- Strong focus on predictive maintenance and cyber-physical systems.

Basque Country's Tknika and Local Industry

Place: Spain

Project: Tknika's Advanced Manufacturing Lab

Tknika, the Basque Centre for Innovation in VET, partners with regional manufacturers (e.g., Danobat Group) to develop training modules where students work on Digital Twin models of machine tools. The initiative includes real-time data acquisition and analysis, supported by IoT platforms.

Link: https://tknika.eus/en/cont/lcamp-the-centre-of-vocational-excellence-in-advanced-manufacturing-kicks-off/

Outcomes:

- Cross-disciplinary training combining mechanical, electrical, and IT skills.
- DT training linked to real production data and machine behavior.
- Alignment with regional smart specialization strategies

MADE Competence Center and ITS Lombardia Meccatronica

Place: Italy

Project: Digital Twin in Smart Manufacturing Paths

MADE, a national Industry 4.0 competence center in Milan, collaborates with ITS Lombardia Meccatronica to co-create learning experiences based on Digital Twin simulations. Training includes the digital modelling of smart factory processes, virtual commissioning, and integration with ERP systems.

Link: https://www.made-cc.eu/en/

Outcomes:

- Co-creation of curricula by industrial engineers and VET trainers.
- Use of DT for factory floor planning and robotics systems.
- Students complete dual-learning modules with company partners.

VET-Keskus and Industry 4.0 Labs

Place: Finland

Project: Simulation-Based Learning in VET for Industrial IoT
VET-Keskus (Vocational Centre) in Tampere partners with software developers and factories to implement Digital Twin platforms in their training labs. The focus is on process industry and industrial IoT.

Outcomes:

- Modular courses on digital process control, simulation, and diagnostics.
- Participation in EU projects like Digital VET 4.0 and DigiPro.
- Teachers trained in agile software deployment for industrial use cases.

Brainport Eindhoven: Digital Twin Learning Factory

Place: Netherlands

Project: The campus hosts a partnership between high-tech manufacturing companies and the Summa College (a vocational college), effectively operating as a "learning factory."

Link: https://www.brainportindustriescampus.com/en/

Outcomes:

- Integrated Training Environment on Digital Twins Solutions.
- VET–Industry Collaboration in the fields of IoT, robotics, and data analytics, with digital twins tying these topics together into practical projects.

These examples illustrate how co-development of training paths between VET institutions and industry actors enhances the relevance and effectiveness of vocational education in Europe. By embedding Digital Twin technologies into curricula, learners gain hands-on experience with the tools and methods shaping the future of work. Such partnerships foster agile, skills-based education aligned with regional innovation ecosystems.

6. Future Trends and Career Opportunities in Digital Twins

6.1 Emerging Trends in Digital Twin Technology

The adoption of Digital Twins (DT) is experiencing exponential growth in strategic sectors such as manufacturing, healthcare, smart cities, and the automotive industry. Companies are increasingly investing in this technology to optimize production processes, predict failures, improve maintenance activities, and make more informed and effective decisions. The application of Digital Twins enables the collection and real-time analysis of data, leading to significant improvements in resource management and the anticipation of future issues.

Key Trends

- Integration with Artificial Intelligence (AI): Digital Twins are becoming increasingly autonomous thanks to predictive models and intelligent simulations, allowing for more precise management and quicker responses to changes in production processes and daily operations.

- Sustainability and Smart Factories: Around 57% of organizations are investing in DTs as tools to improve the sustainability of their activities. With the ability to monitor and optimize energy consumption, reduce waste, and minimize environmental impact, DTs are essential resources for companies moving toward greener, more responsible production.

- Expansion of IoT and Remote Monitoring: The integration of Digital Twins with sensors and connected devices (IoT) is opening up new opportunities for advanced remote monitoring and real-time operational management.

- Cloud and Edge Computing: The use of advanced cloud platforms like AWS IoT TwinMaker and Azure Digital Twins allows companies to efficiently manage real-time data and easily scale their operations. This architecture is crucial for managing the increasing complexity of DT-based systems, enabling flexible and high-performance management.

- Towards Extended Reality (XR): Digital Twins are increasingly integrating with Virtual Reality (VR) and Augmented Reality (AR) technologies, creating immersive experiences that blur the line between the physical and digital worlds. This synergy opens new frontiers in design, simulation, and training, transforming how data is visualized and interpreted.

- Digital Twin as a Service (DTaaS): The emergence of "Digital Twin as a Service" solutions makes the technology more accessible to small and medium-sized enterprises (SMEs), enabling them to benefit from DT capabilities without bearing the high costs of building complex infrastructure.

Interoperability and Standards: The growing adoption of DTs has led to the creation of international alliances and collaborations, such as those among DTC, the OPC Foundation, and Industry 4.0 initiatives. These efforts aim to define common standards to ensure interoperability and integration of Digital Twins from different New Professions and Skills in the Digital Twin World

With the growing adoption of Digital Twins (DT), not only are new professional roles emerging, but existing ones are also undergoing significant transformation. Managing and implementing DTs requires an increasingly broad and multidisciplinary skillset focused on virtual systems, advanced simulations, data analysis, and artificial intelligence. In this context, emerging professions are becoming crucial to tackle technological challenges and support companies in adopting these innovative technologies.

6.2 Emerging Professions

- Digital Twin Engineer: This role is responsible for designing, developing, and maintaining complex digital models that represent plants or processes. They ensure the models are accurate and updated in real time, faithfully reflecting the conditions of physical systems.

- IoT Specialist: This professional manages sensors, collects and analyzes data from connected devices, and links physical objects to their digital counterparts. Their work is vital for maintaining the integrity of the information flow between the physical and digital worlds, ensuring data accuracy and timeliness.

- AI/ML Engineer: These engineers apply artificial intelligence and machine learning models to analyze and predict dynamic behaviors in both virtual and physical environments. Using advanced algorithms, they optimize processes through accurate predictions and real-time automated responses.

- Cybersecurity Expert: With the increasing interconnection between physical and virtual systems, data and communication security is critical. The Cybersecurity Expert protects infrastructure from cyberattacks by monitoring system vulnerabilities and developing defense strategies, including attack simulations to test system resilience.

- Simulation Developer and Data Scientist: These professionals specialize in creating advanced simulations and extracting insights from data. They analyze data collected from DT systems, build predictive models, and generate solutions that continuously improve products, processes, and services.

6.3 Key required skills

To successfully tackle these challenges and meet the demands of a rapidly evolving market, professionals must possess a solid foundation of technical skills, including:

- Programming (Python, Java, C++): The ability to write code for developing applications, simulation models, and interfaces between virtual and physical systems is essential for DT-related roles.
- System Modeling and Simulation: Advanced knowledge of modeling complex systems and creating virtual simulations that replicate real-world behavior is critical to ensuring the effectiveness of DT solutions.
- Data Science and Data Visualization: The ability to collect, analyze, and interpret large volumes of data, and to clearly communicate results, is crucial for optimizing processes and creating data-driven strategies.
- Cloud Technologies (AWS, Azure): Familiarity with cloud platforms is key for real-time data management, operational scalability, and implementing DT solutions that require advanced computing power.
- Artificial Intelligence and Machine Learning: Knowledge of AI/ML algorithms and techniques is necessary for predictive analytics and the ongoing enhancement of systems through intelligent automation.
- Sensor Networks and Internet of Things (IoT): A strong understanding of IoT technologies and sensor network management is vital to ensure seamless integration between physical devices and digital twins.
- Cybersecurity Knowledge: Protecting systems and data is a growing priority, and cybersecurity skills are essential to prevent threats and ensure systems are secure and resilient against potential attacks.

With the evolution of Digital Twins and their expanding applications across sectors, these skills will become increasingly in demand, creating a professional landscape where interdisciplinary collaboration and adaptability to new technologies will be key to business success.

6.4 What Students Need to Learn for the Jobs of the Future

To prepare students to work with Digital Twins (DT) in Industry 4.0 settings, vocational education and training (VET) programs must provide a combination of advanced technical skills and soft skills. Integrating emerging technologies like DT into business practices requires deep technical know-how and a critical, adaptable mindset. Vocational schools play a crucial role in incorporating training modules that address these topics, allowing young people to prepare for increasingly in-demand and well-paid professions in an ever-evolving industrial context.

Technical Skills to Develop

- Programming (Python, R, Java): Students need to gain solid knowledge of commonly used programming languages in tech fields like Python, R, and Java—essential for application development, data management, and interaction with digital models.
- Data Analytics, AI, and Machine Learning: The ability to analyze large datasets and apply AI/ML techniques is key for predictive analysis and efficient DT-based systems management. Students must learn to process and interpret data to optimize processes and make data-driven decisions.
- Cloud Computing: As cloud platforms become central to real-time data storage and management, cloud computing skills are crucial for working with technologies such as AWS, Microsoft Azure, and other cloud solutions used in DT projects.
- Automation and Robotics: Students must be trained in industrial automation and robotics, as these technologies are closely linked to integrating DTs into daily business operations. Understanding automated systems and control techniques is key to optimizing production.
- IoT, Networking, and Industrial Communication Protocols: Knowledge of IoT networks, industrial communication protocols, and connected devices is essential to ensure that DTs can gather real-time data and interact effectively with physical systems. Networking and connectivity skills are thus indispensable for managing device and system interoperability.
- Process Simulation and Modeling: The ability to model and simulate industrial processes using specialized software is fundamental for designing, testing, andoptimizing digital models. Students should gain hands-on experience using simulation tools to create accurate representations of physical systems.

Soft Skills

In addition to technical abilities, soft skills are equally important in helping students face the challenges of the workforce and quickly adapt to new scenarios. These include:

- Critical Thinking and Problem Solving: The ability to logically analyze problems, think critically, and develop innovative solutions is essential, particularly when dealing with complex systems like DTs.
- Collaboration and Communication: The ability to work in teams and communicate clearly is fundamental in increasingly cross-functional work environments. Students should be prepared to collaborate effectively with colleagues, engineers, and specialists from other fields.
- Lifelong Learning Mindset: As DT-related technologies and methods constantly evolve, students must develop a mindset geared toward continuous learning, ready to adapt and update their knowledge regularly.
- Initiative and Creativity: Students should be encouraged to take initiative and propose innovative ideas. A creative, proactive approach is essential to tackle new technological challenges and develop original DT solutions.
- Adaptability to New Tools and Digital Contexts: With the fast-paced evolution of digital technologies, students must be ready to quickly adapt to new tools, software, and digital environments. Flexibility and the ability to learn new technologies are indispensable in the modern industrial landscape.

Initiatives to Support Ongoing Training:

Vocational schools can also promote continuous learning and skills development through various initiatives, including:

- Professional Certifications: Internationally recognized certification programs, such as those offered by AWS, Microsoft, and Siemens, are valuable for ensuring students acquire market-relevant skills. These certifications can also enhance employability by providing professionally recognized qualifications.
- Online Courses via Platforms like Coursera, edX, and Udacity: The availability of online courses offers students opportunities to deepen their knowledge of specific aspects of DTs and emerging technologies. These platforms offer high-quality courses in partnership with top universities and companies.

- School-Industry Partnerships: Vocational schools can establish partnerships with businesses to offer students the chance to work on real-life projects using Digital Twins. This hands-on experience is key to applying theoretical knowledge in professional settings and creating job market connections.

- Virtual Labs and Simulation Environments: To support practical learning, schools can use virtual labs and simulation environments where students can explore and experiment with DTs in safe, controlled conditions. These tools provide an immersive experience that helps students become familiar with the technology before entering the workplace.

Through a combination of technical and soft skills, along with ongoing training opportunities, vocational schools can prepare young people to thrive in an increasingly digital and innovation-driven job market.

Conclusion

As this manual has shown, integrating Digital Twin technology into Vocational Education and Training is not a trend—it is a necessary evolution. The demand for digitally skilled workers continues to grow, and the ability of training institutions to respond with innovative, industry-aligned educational experiences will be critical to the success of both learners and employers.

Digital Twins are much more than virtual replicas—they are gateways to immersive, applied learning. Through simulations, students can engage with real-world challenges, test solutions in safe environments, and develop both technical expertise and soft skills such as problem-solving, collaboration, and critical thinking. These capabilities are at the heart of Industry 4.0 and are essential for navigating the complexities of future workplaces.

Throughout this manual, we have **explored how Digital Twin technology can transform curricula, strengthen ties between education and industry, and support new pedagogical models.** We have seen how co-designing training paths with businesses leads to more relevant and effective learning. The case studies and best practices shared here demonstrate the benefits of collaboration —where companies offer insight and tools, and schools offer talent and educational vision.

We also recognize that implementing Digital Twins in VET is a step-by-step process that **requires planning, investment, and ongoing support.** But the rewards are significant: improved student engagement, stronger employability outcomes, and a closer alignment with the skills required in modern industries. By adopting this approach, schools can become active contributors to regional innovation ecosystems, helping to shape a workforce that is adaptable, forward-thinking, and digitally fluent.

Looking to the future, it is clear that Digital Twin technology will continue to evolve—bringing new opportunities in areas such as AI integration, remote operations, sustainability, and smart manufacturing. For students, this means access to new career paths and lifelong learning options. For educators and institutions, it means an ongoing commitment to experimentation, professional development, and collaboration across sectors.

In conclusion, this manual is both a roadmap and a call to action. By working together—schools, companies, policymakers, and educators—we can ensure that vocational education remains not only relevant but visionary. **Digital Twins offer us the tools; it is up to us to unlock their full potential for the benefit of future generations.**

www.ditwin.eu

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Agenzia nazionale Erasmus+ INAPP. Neither the European Union nor the granting authority can be held responsible for them.

Project Number: 2023-1-IT01-KA220-VET-000154611

Co-funded by the European Union