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The Future of Work and Lifelong Learning

► The digital transformation of apprenticeships: Emerging opportunities and barriers



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- ▶ **The digital transformation of apprenticeships: Emerging opportunities and barriers**

► Foreword

New technologies, demographic shifts, climate change, globalization and more recently the crisis such as global health pandemic are causing major disruptions to the world of work. Against this backdrop, it becomes ever more important to build an agile workforce capable of navigating the fast-changing labour market through appropriate and timely skilling, reskilling and upskilling. The use of apprenticeship models or dual training systems can be an effective solution in the context of the future of work, as it bridges the gap between education and training system and the world of work.

Although apprenticeship is a centuries-old system which enable young persons to acquire skills related to specific occupations, questions are increasingly being raised about its relevance for reskilling and upskilling in the context of the future of work and lifelong learning.

The ILO has therefore launched a research project – *Apprenticeship Development for Universal Lifelong Learning and Training (ADULT)*– which aims to generate new ideas and policy options to modernise apprenticeship systems. The project is funded by the Government of Flanders. The research aims to explore how apprenticeship systems are being modernised and transformed to promote and enable lifelong learning and decent work for youth, adults, and older workers (both employed and unemployed). The research also covers other forms of work-based learning options for students in VET institutes.

The research paper titled “*Digital transformation of apprenticeship systems*” has been produced by the ILO as part of the ADULT project. It explores how digital technology can be used to improve the effectiveness, inclusiveness, and efficiency of apprenticeships. It also highlights the ongoing and emerging innovative practices in using digital and educational technology.

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Ashwani Aggarwal (ILO) managed the research project, led the design and development of this thematic paper and also reviewed, edited and finalized this publication. Anita Sharma (ILO) coordinated with consultants and reviewers and also reviewed and provided comments on the paper.

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► List of acronyms

AA	Advanced analytics
AI	Artificial intelligence
AR	Augmented reality
CC	Creative Commons
ICT	Information and communications technology
IDC	The International Data Corporation
ILO	International Labour Organization
IT	Information technology
LMSs	Learning management systems
LPD	Learning personal documentation
MOOCs	Massive open online courses
NGOs	Non-governmental organizations
OECD	Organisation for Economic Co-operation and Development
OEPs	Open educational practices
OERs	Open educational resources
QABBs	Quality apprenticeship building blocks
SFUTVET	Swiss Federal University for Vocational Education and Training
SMEs	Small and medium enterprises
TVET	Technical and vocational education and training
UNESCO	United Nations Educational, Scientific and Cultural Organization
VR	Virtual reality
XR	Extended reality



Executive Summary

This report examines the added value that digital technologies can provide to the design and delivery of an apprenticeship program. To this end, a literature review, covering scientific and policy examples and other informational materials, was conducted to understand how digital technologies can be applied to enhance the implementation of an apprenticeship program. This report considers the International Labour Organization's (ILO) operationalization of the apprenticeship life cycle (ILO 2020). According to the ILO, the implementation of an apprenticeship programme should be organized in four main stages and 17 sub-phases. The literature review focused on concrete cases of the applications of digital technologies in the 17 operational sub-phases by presenting several evidence-based experiences of technology-enhanced apprenticeship practices collected from different countries, fields and contexts.

In the first stage of developing apprenticeship programmes, two key digital transformation issues were identified: the use of big data for enhancing job market analysis, and the development of a framework to manage digital credentials enhanced by blockchain systems. Big data analytics can be used to map skills by occupation (Boselli et al. 2018), to identify discrepancies or obsolete skills (Mezzanzanica et al. 2018), and to conduct predictive analyses of the demand for new occupations and skills in quasi-real time. According to a recent report from the European Training Foundation (Mezzanzanica and Mercorio 2019), the use of big data for labour market analysis would be especially beneficial in developing and transitioning countries to facilitate the matches between market demand and supply, to design apprenticeship paths to better fit market expectations, and to compare internal labour markets against cross-border countries to facilitate mobility. However, for these countries, a lack of access to administrative and statistical data and a poor level of use of online job advertisements could challenge the reliability of the analysis.

Digital badges and credentials have the potential to promote a competence-based approach during the development of an apprenticeship competence framework. This is particularly relevant when digital badges are developed to be aligned with national frameworks (Konert et al. 2017). However, currently, badge interoperability between different institutions still represents a huge barrier. Effort is required at the national level in various countries to assess which credentials could be recognized or used within apprenticeship programmes. To best exploit digital badges, credential systems for apprenticeship will need to be based on national qualification systems, developed through coordination among different stakeholders.

From a technical perspective, the credential systems can be further supported by blockchain technologies. Blockchain could ensure an additional layer of verification of credentials to prevent or reduce fraud (AkaChain 2020), since apprentices' individual data, such as education and employment history, badges and credentials are associated with a verified ID. Although blockchain technology is still in the early stages, it has the potential to provide users with greater control over their personal data (Christ and Helliard 2021), reducing costs related to apprentices' data management (Grech and Camilleri 2017) and certified paper-based credentials and diplomas (OECD 2021). Since certificates issued on the blockchain can be automatically verified, educational organizations will no longer need to commit resources to this task, significantly reducing their administrative load and practically eliminating the "after-sales support" they need to provide to learners at the end of courses (Grech and Camilleri 2017).

Digital transformation can positively affect the preparation of quality training places, which is the second stage of the apprenticeship life cycle. One of the biggest potential advantages that this report highlights concerns the possibility to better connect all the actors involved in an apprenticeship programme through dedicated digital platforms. The report has described a few platforms (for example, mobile applications

and websites) that have already been adopted to support collaboration among technical and vocational education and training (TVET) teachers, company tutors, trainers for intermediary bodies and apprentices in both developed and developing countries. Although these platforms facilitate communication and exchange, TVET teachers and company tutors need to have the required competences to orient the interactions with each other, as they hold complementary roles, toward apprentices' learning goals. Providing the technology does not guarantee trust and learning exchange among the teachers and tutors. Training everybody – apprentices as well as educators of all kinds – to be comfortable with these platforms is a challenge, which must be overcome in order to benefit from the cross-fertilization between the on-the-job and off-the-job components of learning (Caruso et al. 2020).

Enhancing the digital competences of TVET teachers and trainers as well as apprentices is a pivotal, interrelated issue in the preparation of an apprenticeship programme. Digital competence is more than mere technical skills; it includes a set of knowledge, attitudes and skills that allow the integration of digital technologies critically and purposefully within a learning path. This report has mentioned a few national and international digital competence frameworks for educators. However, the review could not identify any specific framework for educators in various TVET and apprenticeship programmes. Future policy and research would need to focus on a digital competence framework specific to TVET and apprenticeship educators (Lucas et al. 2021; Cattaneo et al. 2022) by including, for instance, context-specific competences, such as those related to using technology to enhance connectivity between apprenticeship learning locations, such as school- and work-based tracks (Cattaneo, Gurtner and Felder 2021).

This report also describes a few innovative technologies that teachers and trainers will be required to adopt more and more for apprenticeship training, which is stage three of the apprenticeship life cycle. Extended reality (XR) solutions, such as augmented reality (AR), virtual reality (VR), 360-degree videos and game-based simulations, could be used to better connect learning in formal and informal contexts. Research shows that XR solutions are at least equal in effectiveness to other training methods, but provide further positive effects related to motivation, engagement and increased interest, as well as the possibility of providing training when danger or cost may make traditional training impossible (Kaplan et al. 2021). XR technologies also have the potential to facilitate learning for apprentices with cognitive and physical disabilities, supporting the development of functional skills such as wayfinding, numeracy, shopping, literacy, emotional and physical competences (Baragash et al. 2020) and job-seeking behaviours.

When it comes to procedural learning, AR especially was found to save time and costs while reducing error rates (Jetter et al. 2018). Some studies found that AR can be used by company tutors to insert digital “annotations” within the physical workplace including virtual images, point-of-view videos, voice recordings and 3D models. The advantage of this method is that it is possible to provide constant feedback to an apprentice at the workplace, even when a company tutor cannot be physically present. Another unique advantage of AR, as compared to other XR technologies, is that it provides the apprentice the opportunity to manipulate physical objects in the workplace and thus, to execute real procedures, such as mechanical assembly or maintenance (Palmarini et al. 2018). VR, on the other hand, provides apprentices with the opportunity to learn within environments that are not accessible for several reasons: they are too far (for example, for apprentices in rural areas), rare or dangerous (for instance, plane crashes¹).

Despite their potential, there are still several limitations related to XR technologies that need to be addressed. Adopting these technologies requires infrastructure (both hardware and software) and human resources able to design VR and AR applications. Issues related to poor application design (such as, response time, graphical issues, and user experience) have a negative effect on apprentices' experiences and consequently on their engagement and learning outcomes. Moreover, if these technologies are used without a careful pedagogical rationale and design, they have no beneficial effect on learning processes. However, these challenges can be overcome in different ways. First, projects that allow teachers and trainers to create their own AR/VR experiences without requiring computer programming skills can be promoted. Second, 360-degree videos allow the creation of immersive experiences without requiring any

¹ For more information, see this VR simulation of a plane crash.

computer programming skills, which is one of the reasons why various studies have reported this option as a cost-effective, immersive technology for education (Roche et al. 2021). To avoid development costs, it is also possible to rely on already developed AR/VR applications for training, such as simulators for building an engine in VR² or cooking simulators,³ in addition to partnering with research centres that can provide competences and resources to implement these technologies in apprenticeship programmes.



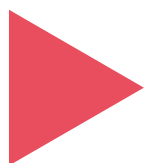
Eventually, digital technologies can be adopted to ensure an effective transition from an apprenticeship programme to future employment/educational opportunities and to assess the effectiveness of the apprenticeship programmes, which is the stage four of the apprenticeship life cycle. Bots trained through machine learning algorithms are currently in use in a few countries (for example, France) to provide individualized counselling based on apprentices' data (D'Silva et al. 2020). Chatbots could potentially provide four levels of career advisory services: offering information and recommendations; providing intervention in career development; augmenting career counsellors' work; and providing career counselling. Artificial intelligence can also be trained to provide individualized counselling by using the same data collected from a labour market analysis based on big data (stage 1).

Technically, one of the key challenges in chatbot development is programming. The creation of a chatbot involves the use of natural language processing, and a chatbot, as a dialogue system, should be able to understand the content of the dialogue and identify users' social and emotional needs during the conversation. Chatbot systems are becoming increasingly effective at providing appropriate answers to users. Despite this, it is advisable to use chatbots in combination with other forms of counselling provided by human experts. Big data analysis methodologies can also be used to collect different kinds of data to assess the effectiveness of an apprenticeship programme, from the more institutional level (educational institution analytics) to the learners and trainers' level (learning analytics). Learning analytics and chatbots will increasingly be based on and driven by algorithms and machine learning. Therefore, decision makers have to consider the risks that algorithms reinforce, maintain or even reshape stereotypes and biases, for example, toward minorities and disadvantaged groups. One of the biggest challenges with chatbots and artificial intelligence is in developing and being compliant with regulatory frameworks that ensure accountability, transparency, and an ethical adoption of learning analytics (Prinsloo and Slade 2017).

This report shows that the digital transformation of apprenticeship ranges from socioeconomic transformation to the inter- and intra-individual psychological experience of each apprentice and trainer. At a broader level, apprenticeship programmes need to keep pace with Industry 4.0 – big data, machine learning, artificial intelligence, robotics and the Internet of Things will continue to shape, to different extents, workplaces and professional practices, providing, on the one hand, an opportunity for sustainable growth and, on the other, risks related to privacy issues, digital colonialism, digital divides and skills obsolescence. This report has also shown that digital technologies could be used to empower communities through meaningful learning experiences, increasing access to knowledge and professional experiences. Many of the good practices presented in this report were driven by individual institutions or partnerships. In the future, coordinated national and international actions will be necessary to support an ethical and empowering digital transformation of apprenticeship in developing countries. Putting the right policies in place will therefore be critical to make apprenticeship programmes and workplaces more sustainable and inclusive.

² For more information, see the Wrench simulation homepage.

³ For more information, see the Cooking Simulator VR page on the Steam Store.



1

Introduction

Introduction

This report aims to address the complex and multifaceted issue of digital transformation in apprenticeship⁴ programmes. We will first provide an overview of Industry 4.0 as one of the main drivers for the digital transformation of apprenticeships, accelerated by the spread of the coronavirus disease (COVID-19) pandemic. We will then present several challenges related to the digital transformation of apprenticeships. Despite these challenges, this report shows that digitalizing apprenticeship programmes could be a worthwhile endeavour. We will try to demonstrate this by reviewing existing literature on how digital technologies could be applied at the different stages of the apprenticeship life cycle (ILO 2017). Overall, our review shows that digital technologies could enhance several traditional functions of apprenticeship designing and delivering. However, policymakers need to critically consider and assess the risks brought on by digital transformation, such as widening social inequalities, reducing people's privacy and controlling their personal data. Throughout this report, we will also present the risks related to specific applications of digital technologies and viable solutions to reduce them at all stages of the apprenticeship life cycle.

► 1.1 Industry 4.0 and new skills requirements

The fast and never-ending digitalization of workplaces has had a huge impact on the design and development of apprenticeship programmes. We are witnessing disruptive transformations brought on by the introduction of Industry 4.0 technologies in almost all economic fields, from agriculture and food industries to manufacturing and services, and in both developed and developing countries (Bogoviz et al. 2019). There are many examples of this shift: smart sensors and drones in the fields of food and agriculture are increasingly used by farmers to obtain real-time information on various parameters, such as chlorophyll concentration, hygrometry, temperature, water potential, radiation or crop stages. Farmers should be able to read and interpret this data to make better-informed and data-driven decisions, such as the use of treatments and pesticides, while considering the consequences of their decisions on the environment (Eyhorn et al. 2019).

The Agriculture 4.0 trend is particularly relevant for developing countries where the agricultural sector often accounts for an important share of the economy (Diem 2020). Manufacturing systems have also been greatly affected by the introduction of traditional and collaborative robots for automating production. While the automotive industry is, historically, the sector with the highest adoption's rate of traditional robots, a growing adoption is also expected in metalworking, plastics and waste management (Bellezza et al. 2018). Due to the lower costs and higher return of investments, collaborative robots are expected to be increasingly adopted by small and medium enterprises (SMEs) as well as in developing countries (Calitz et al. 2017). A recent survey showed that the Internet of Things and other kinds of person-to-machine networked solutions are likely to have a strong impact not only on the manufacturing and automotive sectors, but also on the agriculture, health, consumer, financial and engineering sectors (World Economic Forum 2020).

Dealing with these kinds of disruptive transformations requires considering not only the tangible elements of an apprenticeship program (such as new technological systems and infrastructure) but also the intangible elements, such as professional practices and literacy (including competences and specific skills). The adoption of different Industry 4.0 technologies also comes with a new division of labour, where workers are expected to shift their working day from routine and automatable tasks to

⁴ An apprenticeship is defined as systematic long-term training for a recognized occupation that takes place substantially within an undertaking or under an independent craftsman should be governed by a written contract of apprenticeship and be subject to established standards (ILO 2017).

tasks that are complementary to machines (Spitz-Oener 2006; Autor and Handel 2013). If the human tasks become increasingly complex and demanding, the employment prospects for workers lacking certain skills may decrease (Frey and Osborne 2017). Therefore, apprenticeship programmes should emphasize the development of necessary competences to face these changes, including digital competences (such as computational thinking and digital literacy), as well as transversal and core skills, such as learning how to learn (unlearn and relearn), critical and creative thinking, agility and problem solving (Prifti et al. 2017; Weber et al. 2019). Apprentices can develop these skills within apprenticeship programmes with a digital transformation strategy shared between different learning locations, in the classroom and at the workplace. Of course, this requires some prerequisites to be put into action. Therefore, in the next section, we briefly introduce some of the reasons why the digital transformation of apprenticeship programmes could be challenging.

► 1.2 Barriers to the digital transformation of apprenticeships

Together with Industry 4.0, the COVID-19 pandemic has recently been a driver for the digital transformation of workplaces and apprenticeships. Technical and vocational education and training (TVET) institutions and companies have suddenly realized that they are not sufficiently prepared to provide decent, fully remote learning and working opportunities to apprentices. CEDEFOP (2020b) reported that in many countries, at least the theoretical part of apprenticeship programmes was taught through 100 per cent online solutions. However, the work-based learning component of the apprenticeship was strongly disrupted. This learning is usually based on training in procedural competences, which are particularly difficult to teach without manipulating tools, materials and equipment at school or in the workplace (ILO 2021). In many cases, apprentices were not only unable to attend TVET school because of school closure policies, but they also did not have the chance to access the workplace because non-essential businesses were closed. Consequently, companies were unable to offer or maintain apprenticeship training (OECD 2020).

The closure of TVET schools and companies is only the epiphenomenon of why the shift to online learning during the COVID-19 lockdowns specifically, and the digital transformation of apprenticeships more generally, is challenging. Behind this specific case, the larger issue in the background concerns the lack of adequate infrastructure (including poor or no internet connections, not having a personal device on which to attend online lessons, or a lack of digital skills) and the unequal distribution of a sound and performing digital infrastructure worldwide. According to the International Telecommunication Union (2020), the percentage of households with internet access in developed countries is between 81 per cent (rural areas) and 87 per cent (urban areas) against 28 per cent (rural areas) and 65 per cent (urban areas) in developing countries. The COVID-19 crisis made existing inequalities even more evident in terms of tangible and intangible digital resources in both developed and developing countries.

Previously, data⁵ from the Programme for International Student Assessment (PISA) run by the Organisation for Economic Co-operation and Development (OECD) showed very large gaps across socioeconomic groups in the computer access that learners can use to attend lessons or study from home. Virtually every 15-year-old person in a socioeconomically advantaged school in the United States has a computer at home, but only three out of four students in disadvantaged schools have one. In Mexico, 94 per cent of 15-year-olds from privileged backgrounds have an internet connection in their homes compared to just 29 per cent of those from disadvantaged backgrounds.

⁵ For more information, see the PISA 2018 database.

Moreover, even in cases where access to infrastructure is available, apprentices from disadvantaged socioeconomic backgrounds did not have adequate spaces at home for learning and or receive adequate support from their families (including sometimes having to share devices with family members). The COVID-19 crisis has dramatically confirmed that the unequal distribution of infrastructure and hardware is no longer acceptable as these are essential preconditions for accessing and participating in education and training in both the workplace and broader society. Although issues related to infrastructure and digital skills have been particularly serious in developing countries during the pandemic, similar challenges were reported also in developed countries (Delcker and Ifenthaler 2021). If this general situation were not enough, evidence confirms that vulnerable groups, who are often served by the TVET system, were the most affected by issues related to the digital divide during the pandemic.

The lack of access to technology and of resources has been a barrier to the digital transformation of apprenticeship programmes prior to the COVID-19 pandemic as well (Sicilia 2005). Having said that, good infrastructure is a necessary but not sufficient condition for the digital transformation of apprenticeship providers.

As with equipment and technology, strategy and leadership can facilitate, or challenge, the digital transformation of apprenticeship providers (Ifenthaler and Egloffstein 2020). Research shows that when TVET schools foster an open debate around the integration of digital technologies into training practices, TVET teachers perceive digital technologies as an opportunity to improve apprentices' learning outcomes. However, this is not always the case, especially when the digital transformation strategy is based on authority or bureaucratic influence (Navaridas-Nalda et al. 2020).

In the context of apprenticeship, the absence of a shared vision or strategy between TVET schools and companies could be a barrier to an effective digital transformation. This concept has been defined as "school-workplace connectivity" (Stenström and Tynjälä 2009), which can be supported by the following factors: the degree of coordination and collaboration between the various bodies involved in the TVET system at the macro-institutional level; the quality of TVET curricula in relation to the new demands of the labour market (including digital competences); the development of integrative pedagogical approaches; and the ability of teachers and trainers to guide and support apprentices effectively (Sappa and Aprea 2014).

Even with infrastructure and an established strategy, digital transformation eventually needs to be enacted by each actor of the system (including, apprentices, TVET teachers and company and inter-company trainers⁶). Without the active participation of these stakeholders, the digital transformation of apprenticeships cannot take place (Cattaneo, Gurtner and Felder 2021). There are different reasons why trainers and apprentices could be more or less ready to use technology in training and learning. Trainers' beliefs, personal values and attitudes appear to be strong contributing factors in their efforts to use technology, even when they work with a limited amount of resources or time (Ertmer et al. 2006; Ottenbreit-Leftwich et al. 2010; Tondeur et al. 2017; Lucas et al. 2021). The digital transformation of apprenticeships requires teachers and trainers to develop an open and analytical attitude toward the use of digital technologies, which does not mean being acritical or techno-optimistic (Tomczyk et al. 2021), but rather able to assess when digital technologies could be adopted (or not) to pursue specific learning objectives.

Tsai and Chai (2012) suggested that teachers struggle when they try to creatively restructure the learning environment using digital technologies. Literature shows that trainers who are beginning to use technology to support their training tend to use it to replace previous practices by transferring an

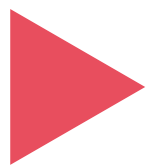
⁶ Company trainers are individuals responsible for imparting practical training to apprentices and for introducing them into their work during the on-the-job part of their training. TVET teachers are employees of TVET schools, and they are responsible for planning, organizing and delivering off-the-job and theory-oriented training. In some TVET systems (such as in Germany and Switzerland) inter-company trainers provide complementary TVET, also offering advanced training and continuing education as well as occupational guidance and preparation (CEDEFOP 2020a).

existing pedagogical practice into a newer medium with no functional improvement (Kimmons et al. 2020). The lack of instructional design is related to the low levels of digital competence in trainers, which can be defined as a set of knowledge, skills and attitudes necessary to adopt digital technologies for educational purposes (Redecker and Punie 2017). In a meta-analysis, Bingimlas (2009) reported the lack of confidence, competence and access to resources as major obstacles in the use of technology in teaching and learning environments. A low level of technological knowledge and confidence makes educators anxious about using technology with their apprentices, and these factors influence educators' motivations to use technology.

Not only with respect to trainers, but factors related to apprentices can also be barriers to digital transformation. According to the Survey of Adult Skills (2015), carried out within the OECD's Programme for the International Assessment of Adult Competencies (PIAAC) across OECD countries, on average, approximately 80 per cent of young TVET graduates can at least solve basic problems using information and communications technology (ICT). This percentage is lower than the share of young adults with a general educational qualification (at the same level) as well as those with tertiary educational qualifications who participated in the PIAAC survey.

Interestingly, in the United States and Japan, TVET graduates perform significantly better than graduates from general education programmes at PIAAC problem-solving tasks using ICT. In Chile, Poland and Lithuania, only approximately 60 per cent of young TVET graduates went beyond the basic level of digital competency. Again, the differences in the levels of internet access and available infrastructure can explain part of the variation in adult digital competence levels across countries (Kuhlemeier and Hemker 2007; Zhong 2011).





2 Digital transformation in the apprenticeship life cycle

Digital transformation in the apprenticeship life cycle

Despite the general challenges discussed in the previous chapter, this report shows that the digital transformation of apprenticeships can be a worthwhile endeavour in the implementation of apprenticeship programmes.

Specifically, this report focusses on the added value that digital technologies can provide to the design and delivery of an apprenticeship program. To achieve this aim, a literature review was conducted, including scientific and policy examples and other informational materials with the aim to answer the following research question:

How can digital technologies be applied to enhance the implementation of an apprenticeship program?

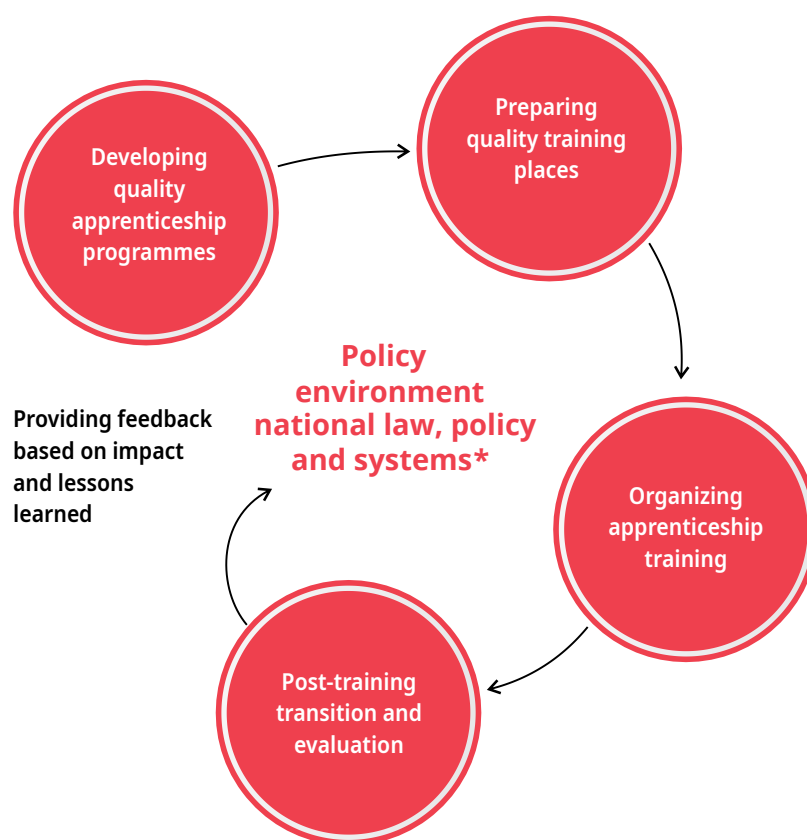
To answer this question, the authors considered the International Labour Organization's (ILO) operationalization of the apprenticeship life cycle (ILO 2020a). We chose to adopt the apprenticeship life cycle as a framework mainly because of the following two reasons:

- ▶ Presenting evidence: The life cycle provides a set of concrete phases that can be linked to technology-enhanced practices. Thus, it provides clear guidelines for researching and presenting technological solutions and practices to ensure and improve the quality at each sub-phase of the apprenticeship life cycle;
- ▶ Informing policymakers and future research: The emergence of innovative practices in each sub-phase of the quality apprenticeship life cycle are useful to not only practitioners. National laws, policies and systems could also identify effective strategies to adopt at a more systemic level.

According to the ILO, the implementation of an apprenticeship programme should be organized into four main stages and 17 sub-phases (see table 1 in the next chapter for more details). The development of programmes is undertaken in stage 1, preceding, or sometimes carried out simultaneously with, stage 2, the preparation of training places. Once the required preparations are in place, apprenticeship programmes can be organized and delivered in stage 3. After completing the programmes, stage 4, each apprentice's subsequent transition into employment or further education and training becomes one of the elements in the evaluation process. Although the apprenticeship life cycle is mainly devoted to practitioners (those involved in implementing apprenticeship programmes), the programme's evaluation informs the development or revision of national laws, policies and systems, which, in turn, brings about improvements to the four stages of the quality apprenticeship life cycle (see figure 1).

⁴ An apprenticeship is defined as systematic long-term training for a recognized occupation that takes place substantially within an undertaking or under an independent craftsman should be governed by a written contract of apprenticeship and be subject to established standards (ILO 2017).

Figure 1 The quality apprenticeship life cycle

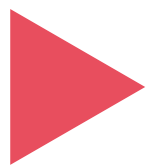


***The six building blocks of quality apprenticeship systems:**

Meaningful social dialogue	Robust regulatory framework	Clear roles and responsibilities	Equitable funding arrangements	Strong labour market relevance	Inclusiveness
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Source: ILO (2020a).

Therefore, the literature review focused on concrete cases and applications of digital technologies in the 17 operational sub-phases. We will first present a summary of our results and then go through each of the digital applications/practices identified without neglecting their risks and drawbacks. Whenever possible, for each digital application/practice, we will also show the possible implications for the six quality pillars of an apprenticeship system (ILO 2017): 1) a meaningful social dialogue; 2) a robust regulatory framework; 3) clear roles and responsibilities; 4) equitable funding arrangements; 5) labour market relevance; and 6) inclusiveness.



3 Integrating technology in the apprenticeship life cycle

Integrating technology in the apprenticeship life cycle

The results of our literature review are summarized in table 1, which presents illustrative examples of digital technologies and/or practices that can be adopted to enhance a specific sub-phase of the apprenticeship life cycle. The association between the digital technologies presented and the sub-phases should not be interpreted as definitive (a specific digital technology could be also adopted to enhance other sub-phases of the apprenticeship life cycle) nor exhaustive (the examples have only an illustrative aim). However, in this report we will try to avoid redundancy and present a specific digital technology/practice in only one or two sub-phases at most.

In the next sections, we will describe the different technologies we propose to enhance and transform all the stages and processes/sub-phases of the ILO apprenticeship life cycle in greater detail, as well as demonstrate their connection with the building blocks of quality apprenticeship systems.

Table 1. Examples of digital technologies and practices related to the 17 sub-phases of the apprenticeship life cycle

Stages of the apprenticeship life cycle	Processes/sub-phases	Illustrative examples of digital technologies and practices related to the sub-phase
Stage 1: Developing a quality apprenticeship program	1. Establishing an institutional framework for social dialogue	Social media and online forums (section 3.1.1)
	2. Identifying skills needs in sectors and occupations	Big data and artificial intelligence (AI) (section 3.1.2)
	3. Developing occupational profiles and curricula based on skills needs assessment	Digital open badge (section 3.1.3)
	4. Providing instructional and learning materials	Open educational resources (OERs), open educational practices (OEPs) (section 3.1.4), and learning management systems (LMSs) (section 3.1.4.1)
Stage 2: Preparing quality training places	1. Engaging and registering enterprises to provide apprenticeship training	Online portal (section 3.2.1)
	2. Formulating apprenticeship agreements	E-signature and digital signature (section 3.2.2)
	3. Building partnership in apprenticeships programmes	Platforms to interconnect workplace and TVET schools (section 3.2.3)
	4. Ensuring the capacity of TVET providers to provide the off-the-job component of apprenticeships	Massive open online courses (MOOCs) (section 3.2.4)
	5. Preparing staff to train and mentor apprentices	Digital skills framework and digital animator profiles (section 3.2.5)

Stages of the apprenticeship life cycle	Processes/sub-phases	Illustrative examples of digital technologies and practices related to the sub-phase
Stage 3: Organizing apprenticeship training	1. Attracting candidates to join apprenticeship trainings	Video-based technologies (section 3.3.1)
	2. Recruiting apprentices	Job boards, AI and blockchain (section 3.3.2)
	3. Developing a training plan	Project management and productivity tools (section 3.3.3)
	4. Effective training delivery methods	Pedagogical models (3.3.4) for an effective adoption of augmented reality (AR) (section 3.3.4.1), annotation tools (section 3.3.4.2), and virtual reality (VR) (section 3.3.4.3)
	5. Monitoring, assessment and certification	E-portfolio and game-based assessments (section 3.3.5)
	6. Social inclusion	Assistive technologies (section 3.3.6)
Stage 4: Post training transitions and evaluation	1. Transition to the labour market or into further education and training	Social media, job placement services and virtual assistant chatbots based on AI (section 3.4.1)
	2. Evaluation of quality apprenticeship programmes	Learning analytics (section 3.4.2)

Source: ILO (2020a).

► 3.1 Stage 1: Developing a quality apprenticeship program

Developing an apprenticeship programme is the first stage of the apprenticeship life cycle. At this stage, practitioners should closely align the programme with both labour market demands and the country's qualification system. As shown in table 1, the first stage can be divided into four main processes: 1) establishing an institutional framework for social dialogue; 2) identifying skills needs in sectors and occupations; 3) developing occupational profiles and curricula based on a skill needs assessment; and 4) providing instructional and learning materials. In the following sections, it will be demonstrated how digital technologies can be used to enhance the effectiveness and efficiency of these four main processes.

3.1.1 Supporting social dialogue among apprenticeship stakeholders: Social media and online forums

Meaningful social dialogue is one of the six building blocks of quality apprenticeship systems (ILO 2017). Digital technologies could facilitate engagement among social partners within a wider network of stakeholders at the international, national, sectoral and local levels.

Online services such as websites, digital media engagement and social media platforms can be adopted to engage stakeholders who are geographically dispersed at the international and national levels through the development of online communities (see box 1). Online communities enable members with common interests or goals to collaborate and interact virtually. Online community platforms can facilitate interactions among individuals as well as community building through different kinds of functionalities, from rating systems for assessing and tracking ideas to monitoring decision-making processes (Barrett et al. 2016). While offering opportunities for social dialogue, online community management may also prove challenging, especially in terms of guaranteeing sustainable collaborations over time. The success or failure of an online community depends, in part, on an organization's commitment to sustained organizational and financial support for dedicated community management. To build a thriving online community, organizations must ensure they have political and organizational commitment and the financial and human resources to not only to start an online community but also support its growth and evolution throughout its life cycle. Before deciding whether to start an online community, decision-makers should investigate whether their proposed community differs from existing ones, and whether it makes more sense to seek collaborative opportunities with an established community instead (Young 2013).

Box 1. Support for social dialogue among apprenticeship stakeholders through social media and online forums

The European Alliance for Apprenticeship established a group on the social media platform LinkedIn administered by the European Commission Directorate-General for Employment, Social Affairs and Inclusion.⁷ The group includes governmental representatives, TVET providers, apprenticeship providers and other apprenticeships experts.

The Platform of Expertise in Vocational Education (Plateforme d'expertise en formation professionnelle, PEFOP⁸) offered space for a forum⁹ aiming to support networking and exchanges between TVET and apprenticeship actors in Africa. The forum offers a directory of members to encourage direct exchanges and the development of collaborative activities between actors.

Skillsnet is a networking and information platform that brings together players in Swiss apprenticeship programmes and reshapes their cooperation and exchange. Skillsnet was created to ensure a transfer of experience and knowledge and encourage networking among apprenticeship stakeholders. One of the goals of Skillsnet is to optimize the interaction between the three training locations in the Swiss context (the TVET school, the workplace and inter-company courses).

3.1.2 Using big data to identify and anticipate skills needs in various sectors and occupations

Skills assessment and anticipation exercises are often undertaken to assess current and future skills needs to enable countries to respond effectively to changes and imbalances in the labour market (ILO 2015; OECD 2016). Policymakers need faster and more detailed information on skills to monitor and quickly respond to challenges created by economic and societal megatrends, such as Industry 4.0 and the transition towards more sustainable economies. Data sources available online can be exploited almost in real time and have the potential to improve policymakers' understanding of the trends in both skills demand and supply. Big data analysis can support the forecasting of which skills are needed to reduce the skills gaps by detailing and adapting skills anticipation (CEDEFOP et al. 2021).

⁷ For more information, see EAfA - European Alliance for Apprenticeships on LinkedIn.

⁸ For more information, see the Plateforme d'expertise en formation professionnelle website.

⁹ For more information, see the Forum for TVET page on the PEFOP website.

There are different online data sources that can be used to complement the traditional methods used to identify and anticipate skills needs (see table 2) including:

- online job advertisements as a source to identify skills demand;
- online CVs shared in job portals and social media profiles as sources to identify skills supply;
- electronic patent and scientific paper repositories as sources to anticipate future skills demand;
- education and training programmes and curricula as sources to predict future skills supply.

Table 2. Big data sources for analyses of skills needs

	Skills demand	Skills supply
Current	Online job advertisements;	Online CVs; social media profiles
Future	Electronic patent; scientific paper repositories;	Education and training programmes and curricula

Source: Authors' analysis

These sources usually offer complementary information (see figure 2), which allows the detection of mismatches between skills demand and supply. Analysing the content of apprenticeship programmes and their expected outcomes, such as programme descriptions, curricula, learning outcomes/skills and qualifications, can provide insights into gaps between education and training provisions and employers' skills needs. Electronic patents and scientific paper repositories can be analysed to better understand the skills needs arising from the spread and adoption of Industry 4.0 technologies. The results of this analysis can possibly be used to develop training programmes aimed at reducing the existing skills gap (see box 2).

Box 2. Using big data analysis to identify training opportunities to bridge the gap between skills demand and supply

The Flemish public employment service uses text analytics on online job advertisements and CVs to match open positions to jobseekers and identify training opportunities that bridge the gap between jobseekers' skills and employers' demands. The Competent database,¹⁰ which was developed with social partners, is used as the main tool to link qualifications and work experience to skills requirements. This approach has also been successfully implemented in Malta.

It should be noted that all these data sources were not primarily designed for labour market and skills analysis. These massive, unstructured data pose various challenges for analysis, and they require processing through comprehensive and robust systems before being analysed. Developing such systems is a complicated and resource-intensive endeavour, but it can pay off in the long run since it provides real-time and detailed information on skills needs.

¹⁰ For more information, see the Competent Database page on the CEDEFOP website.

Figure 2. Complementary information typically contained in online CVs and job advertisements



Source: CEDEFOP et al. (2021).

Automatic content analysis of online job advertisements, usually supported by natural language processing techniques, presents different advantages (Rios et al. 2020; Yazdanian et al. 2020). Since job advertisements usually require describing the required skills in a limited number of words, employers are likely to select the skills that are most desirable and difficult to find in the applicant pool (Burning Glass Technologies 2015). The key skills desired can be easily linked to specific positions, fields, minimum education requirements and any other information introduced in a job advertisement. Moreover, trends analysis can be undertaken because data can be collected frequently.

However, there are also other possible methodological limitations that need to be addressed. Since employers' needs evolve rapidly, the results of an automatic content analysis can only be valid in a short-term perspective (Gardiner et al. 2018). The only ways to overcome this limitation are to reproduce this process frequently, which can be expensive, or to apply more evolved machine learning techniques to the process of content analysis that still require development and testing (Yazdanian et al. 2020).

The share of vacancies published online in the European Union (EU) ranges from under 50 per cent to almost 100 per cent, with some countries reporting annual growth rates in online job markets of over 10 per cent (ILO 2020b). Carnevale et al. (2014) estimated that between 60 and 70 per cent of job openings in the United States were posted on the internet, although these job advertisements were biased toward industries and occupations that seek high-skilled, white collar workers. In low-income countries, such biases can be more challenging to overcome. Higher informal employment and a less-developed digital infrastructure means that online recruitment covers only a small part of the job market, particularly urban, formal and white collar jobs (Hiranrat and Harncharnchai 2018). Another challenge is related to the completeness of the information included in the online job advertisement, since the skills listed in a vacancy notice do not necessarily reflect the full job profile. For these reasons, big data from online job search platforms can be used only to complement traditional labour market analyses (see box 3).

Box 3. Complementing big data with traditional labour market analyses

The United Nations Educational, Scientific and Cultural Organization (UNESCO) uses labour market data to identify and anticipate trends to inform Member States about the future of skills supply and demand in the labour market within the framework of its TVET strategy. It also supports the development of data-backed policies and programmes, demonstrating a potential for combining traditional labour market analyses with big data from online job search platforms.

In Malawi¹¹ and Myanmar,¹² UNESCO mined data from local job portals, and job titles were mapped using JobKred's taxonomy.¹³ The frequency of mapped job titles was used as an indicator of employer demand in the labour market. Subsequently, job descriptions were processed by JobKred's predictive engine to identify relevant skills. UNESCO plans to use big data from job portals to support evidence-based TVET policies for the Youth Employment in the Mediterranean project. A partnership with McKinsey & Company to test the power of advanced analytics in education is in place in Malawi and Myanmar. UNESCO recommends that governments and stakeholders ensure the ethical, transparent and auditable use of data, while being cognizant of the dilemmas of balancing open access to data and data privacy protection. The agency advocates being mindful of the legal issues and ethical risks related to data ownership, data privacy and public data availability (UNESCO 2019a).

At this stage of technological development, big data analysis has to be used cautiously by generating evidence that complements other types of skills intelligence, such as skills forecasts, analyses based on surveys and administrative data. Big data analysis is not possible without a human contribution in collection, analysis, validation and interpretation. It is the combination of artificial and human intelligence that will be central to developing big data's role in shaping effective TVET and skills policies in the coming years. This will require new skills for job analyst experts, such as a set of AI literacy skills required for effective human-machine collaboration.

Deciding to adopt AI-based solutions demands the serious consideration of possible ethical issues. Machine intelligence learns primarily from observing data that it is presented with. While a machine's ability to process large volumes of data may address this in part, it is true that if that data is laden with stereotypical concepts of gender, race and class, the resulting application of technology will perpetuate these biases (Leavy 2018). Being aware that ideology is embedded in language will help prevent the generation of biased algorithms in machine learning approaches to texts, including job advertisements.

3.1.3 Digital badges for competence

In many countries, apprenticeship programmes are based on competence-based qualification requirements, and digital open badges can be used to promote competence-based qualifications (Brauer et al. 2018). Digital badges are defined by SURFnet as "digital pictograms or logos that can be shared across the web to show the accomplishment of certain skills and knowledge" (SURFnet 2016). The skills and experience to which they attest are highly variable and range from general to specialized skills and knowledge, and from cognitive to non-cognitive skills (Kato et al. 2020). Previous experience shows that digital badges could be designed to be aligned with cross-national competency frameworks, such as the European Skills Framework (Konert et al. 2017). Digital badges can also be used in different ways in an apprenticeship program including: 1) To recognize competences acquired before or during

11 For more information, see TEVET policy review: Malawi.

12 For more information, see TVET system review: Myanmar.

13 For more information, see the JobKred website, <https://www.jobkred.com/>.

an apprenticeship programme through external courses or other informal learning experiences; and 2) to recognize competences acquired within an apprenticeship programme (at school or the workplace). Besides the advantage of recognizing learning in multiple and diverse locations and environments, open badges could support apprentices' motivations through reward mechanisms and/or attention since they can be used to track a trajectory through a curriculum (Jovanovic and Devedzic 2014).

Digital badges are considered important tools in ensuring that progress made outside a formal apprenticeship programme (for example, through online courses or direct practice) can be appropriately rewarded with qualifications in a timely and effective manner (OECD 2020). Apprenticeship providers can decide to recognize and embed professional digital badges delivered by externally recognized institutions (see Box 4) or national authorities to acknowledge the development of core, digital and entrepreneurial skills acquired by apprentices before or during an apprenticeship programme (Zanville et al. 2017). Individual apprenticeship providers might enable apprentices to take short courses leading to badges that are not part of their actual apprenticeship programme, but which augment their skills.

Box 4. Online badge providers

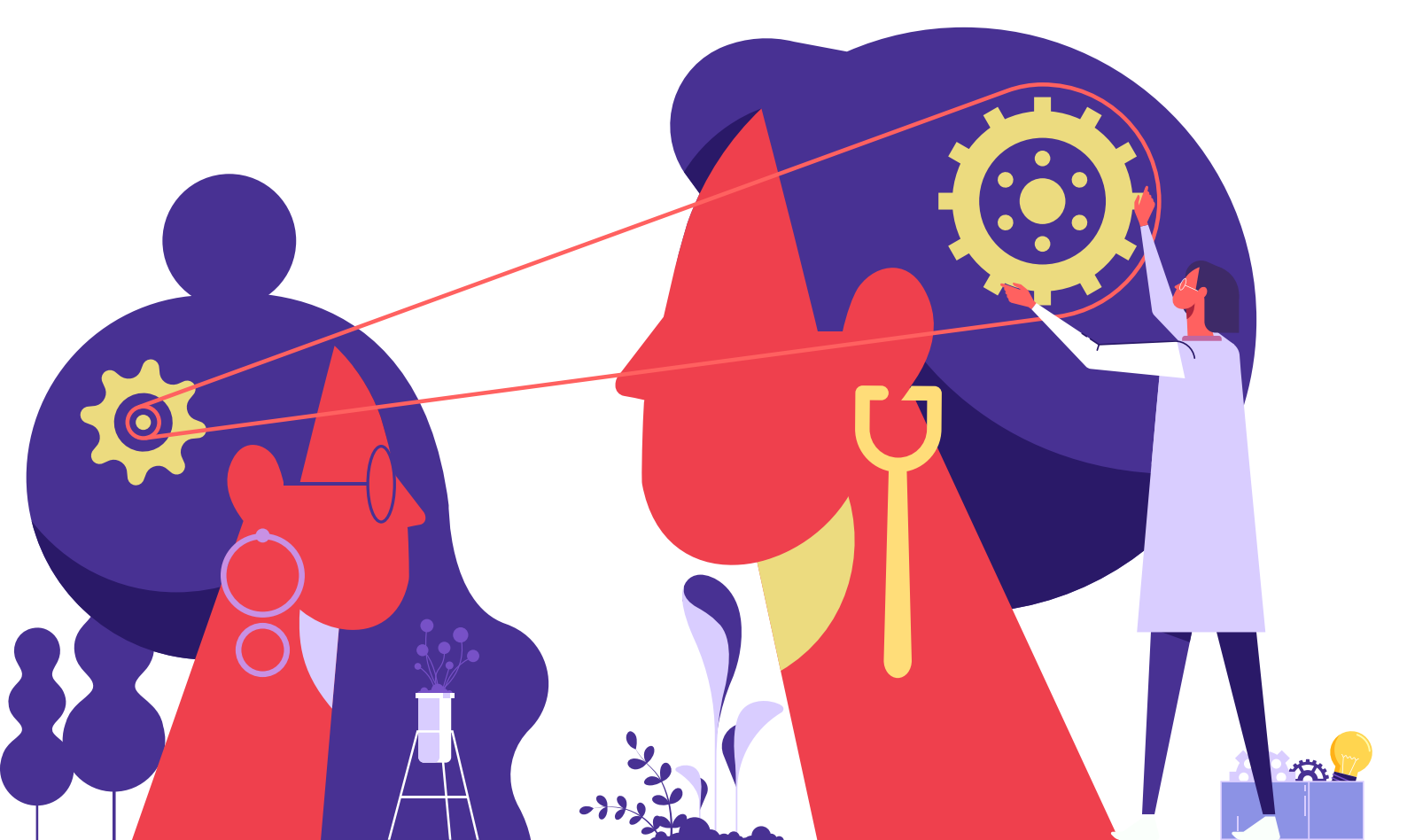
Large firms, particularly technology firms, have been providing the opportunity to earn digital badges after completion of an online programme to the wider public. Amazon, Cisco, Google, Microsoft and other technology companies actively provide digital badge programmes focusing on information technology, particularly in emerging technology areas, including AI and cybersecurity.

In 2019, LinkedIn announced the launch of a skills assessment tool that validates LinkedIn users' skills and knowledge by issuing digital badges, creating an integrated suite of products – training assessment, badging and dissemination – on their platform.

SkillCheck is a tool created by Unionlearn in the United Kingdom for unions to use to deliver learning in the workplace. The tool contains learning themes for badges designed to help engage learners, providing a way for both an initial assessment and to encourage further learning. Specific badges for apprentices have been developed, which also include ICT skills, everyday finances, and green skills and environmental awareness.¹⁴

Digital badges can be also acknowledged within an apprenticeship programme itself, for instance, by a company that provides on-the-job training. In some cases, companies rely on an internal badge system for their employees, which can also be beneficial for apprentices (see box 5). A less expensive solution for companies could be to rely on an open-source LMS to manage their badge programmes, such as Moodle or WordPress (see section 3.1.4.1). On Moodle, a badge can be awarded by completing either a single course or a curriculum of courses, or by completing individual activities or tasks within a course (Abernour 2016). A limitation of this kind of badge concerns the definition of what has been recognized with a specific badge and the terminology used to express that. This is especially the case with transversal and core skills (for example, creativity and teamwork), which could be interpreted in different ways by different individuals/organizations, leading to the issuing of badges based on divergent understandings of what these skills mean and how they should be measured. In other words, there is a need for consistency in the definition of knowledge, skills or competences that a badge stands to represent.

¹⁴ For more information, see the Apprenticeship Badge page on the Unionlearn website.



Box 5. Badge systems built internally by enterprises

The National Health Service (NHS) in the United Kingdom ran the Open Badge pilot programmes in two of their regional organizations. NHS employers shared informal and formal learning activity data, as well as reflective statements, in an xAPI¹⁵ Learning Record Store. To achieve a badge award, employers had to undertake a formal learning course and be part of a reflective practice.

In 2015, IBM launched a badge programme to offer a means of verified proof of achievement, seeing value in the accompanying metadata that describes the rigorous process required to achieve a qualification. The programme has four badge types:

1. the explorer badge, for the early stages of knowledge and skills acquisition;
2. the advocate badge, for higher levels of proficiency in a specific area of interest;
3. the certified badge, for participants who have achieved formal certification through proctored exams;
4. the inventor badge, for those who can prove their ability to design and implement complex technology solutions and applications (IBM 2015).

IBM also acknowledges specific badges available only to apprenticeship employees.¹⁶

However, these issues can be limited by developing badge systems coordinated at the national level with the cooperation of employers' associations or trade unions (see box 6). This latest possibility guarantees a higher comparability of badge certification across programmes nationally or internationally (Finkelstein et al. 2013). In the future, digital badges would need to fit into national qualifications systems to formally count as part of an apprenticeship. Currently, we are still in the early stages of this development.¹⁷

¹⁵ For more information, see the Learning Record Store on the xAPI website.

¹⁶ For more information, see the Badges: IBM Apprenticeship Program page on the IBM website.

¹⁷ For more information, see The role of micro-credentials in facilitating learning for employment.

Box 6. Badge systems developed by employers' associations

The Manufacturing Institute in the United States built the National Manufacturing Badge System,¹⁸ recognizing the wide range of skills, competencies, capacities, qualities and achievements that students and workers need to be successful in today's advanced manufacturing workplace, which they can acquire through their participation in a few world-class youth and worker development organizations partnered with the institute. The National Manufacturing Badge System and the badges it supports will supplement formal learning requirements and pathways and will give individuals an additional platform (based online) to instantly convey to employers what they know and what skills and experiences they bring to the table.

Besides the stated benefits, there are also certain concerns regarding open badges. First, apprentices might focus on accumulating badges rather than on learning the associated activities or materials. One approach could be to design not only badges aimed at recognizing achievements, but also badges that award earners certain roles associated with both privileges and responsibilities in the learning community (for example, becoming moderators, facilitators or editors). While the former kind of badge only assesses learning goals, the latter become “means” for further learning (Põldoja 2009).

Second, there is the issue of understanding what badges say about a learner, especially when many kinds of badges are integrated into a person's competence profile. One approach to overcome this problem is to provide apprentices with tools that would allow them to easily develop custom (or context-specific) competence profiles through the curation of their badges.

A third major issue concerns badge interoperability, which means that a badge acquired from an institution should be acknowledged by other institutions. To this end, blockchain technologies could provide some solutions (see section 3.3.2).

3.1.4 Instructional material for teachers and trainers: OERs and practices

Teachers and trainers need instructional materials and tools to improve the effectiveness of the learning process, cater to the special needs of learners, and increase outreach to learners in remote areas and to those with learning disabilities.

Traditional instructional materials, such as printed textbooks, are to a large extent restricted by copyright. However, in the current digital age, the sharing of information has become easier and more convenient while incurring almost no additional costs.

This opportunity was particularly evident during the pandemic, when trainers and teachers were invited to search, adapt and reuse existing OERs available in national and international repositories to overcome time limitations in preparing online learning content (Huang et al. 2020). OERs are learning, teaching and research materials in any format or medium that reside in the public domain or are under a copyright that has been released under an open license that permits no-cost access, use, reuse, repurposing, adaptation and redistribution by others (UNESCO 2019b). OERs not only comprise individual course components (for example, open textbooks, lecture notes, assignments and videos) but also a whole course, a content management software, authoring tools and implementation resources such as standards and licensing tools for publishing digital resources (Poce et al. 2020).

¹⁸ For more information, see Manufacturing Institute: Badges for Informal Learning and Experiences (dmlcompetition.net).

- ▶ Enhance collaboration and networking, fostering a sharing culture and respect for various cultures and beliefs (Tappeiner et al. 2019).
- ▶ Ensure that learners with diverse needs and preferences (for example, learners with disabilities) have equal opportunities in accessing learning resources, services and experiences in general (Zhang et al. 2020).
- ▶ Help teachers and trainers save time while preparing learning materials (Blackall and Hegarty 2011) and benefit from content developed by peer-teachers.
- ▶ Achieve learning outcomes comparable to studying traditional textbooks (Hilton 2016).
- ▶ Empower learners as co-producers on their lifelong learning paths (Ehlers 2011).

1. searching and selecting (for example, using specific OER repositories, see box 7);
2. creating, adapting and modifying;
3. managing, protecting and sharing (for example, selecting the proper CC license).

Many of these skills do not seem to be well developed in teachers. Preliminary findings from an OECD survey on OERs showed a low awareness regarding the importance of using open licenses among teachers and researchers producing learning resources and few initiatives from institutions to accommodate this deficiency (Hylén 2021). Since many OER repositories allow any user to create an account and post material, some resources may not be relevant and/or accurate, and for this reason the ability to search for and select high-quality OERs is critical for teachers.



Box 7. OER repositories for TVET and apprenticeship programmes

The TVET Academy¹⁹ offers vocational training materials for disadvantaged youth in developing countries, primarily through OERs, which can be used by both trainers and learners. A download function provides the option to use resources in remote areas using standalone projectors. The TVET Academy provides training in entrepreneurship, sustainable development and life skills. Examples of available jobs include those in hospitality and catering, cooking, building and public works, masonry and electrical work.

The TESDA Online programme is an OER platform that aims to make technical education more accessible to Filipino citizens through distance education, with content on agriculture, automotives, electronics, entrepreneurship, human health and healthcare, heating, ventilation, air conditioning and refrigeration, ICT, lifelong learning skills, maritime and social studies, community development and other services and tourism-related vocations.

UNESCO-UNEVOC has compiled a list of platforms and services that provide or facilitate access to open license content for TVET. The list contains services with an explicit focus on vocational education, but also includes others that do not exclusively feature TVET content.

Studies show that accessing OERs requires learners to have a high level of self-regulating skills (Kim et al. 2020). Some learners begin learning by opening resources on platforms but fail to maintain engagement when faced with difficult problems. Other learners show consistently low engagement with these platforms and stop using them without further exploration (Muir 2014). In order to support a higher level of engagement with OERs, attention has shifted from content delivery approaches, which focus on educational resources, to more practice-centred ones (for example, OEPs) that foster collaborations between learners and teachers to create and share knowledge (Cronin 2017). OEPs engage learners in creating and revising OERs, thus contributing to the learning of the learners who come after them. This can further help learners gain digital literacy skills (for example, searching, assessing and identifying online resources), which are fundamental for twenty-first century literacy (see box 8).

There are some additional challenges related to OERs that need to be addressed in the context of apprenticeships. The first challenge concerns the sustainability of OER initiatives. Since creators generally do not receive any payment for their OER, there may be little incentive for them to update it or ensure that it will continue to be available online. Second, although efforts are being made to make OERs available in multiple languages, many are only available in English, limiting their usefulness to non-English speakers. In addition, not all resources are culturally appropriate for all audiences, and the usability of the content can strongly depend on context. Finally, the use of some OERs can be confined to the school-based component of an apprenticeship program with lower applicability to the workplace.

¹⁹ For more information, see the TVET Academy website, <https://tvvet-academy.de/>.

Box 8. Open educational practices in formal and informal apprenticeship contexts

Digital Green has joined forces with governments, private agencies and rural communities to co-create digital solutions to improve agricultural practices in India, Ethiopia and Nigeria. Various partners and communities have produced more than 6,000 locally relevant videos in 54 languages with CC licenses about productive farming, health and conservation practices. These videos are used by trainers to effectively support evidence-based agricultural practices in informal apprenticeship programmes. In Ethiopia, the community video approach has been incorporated into the country's National Agricultural Extension Strategy, allowing it to reach over 420,000 farmers.

Within the contexts of the Erasmus + Project KNORK (Knowledge + Work) environments, different OEP case studies have been collected from school-based apprenticeship programmes.²⁰ For example, in an Italian TVET school, cook apprentices were asked to collaboratively co-design a guide for a combi oven-convention steamer to support both their professional skills and theoretical knowledge of physics.²¹

3.1.4.1 Organizing instructional materials through learning management systems

At both TVET schools and companies, teachers and trainers may perceive the need to manage learning content and materials to be used with apprentices. Learning content management systems (LCMSs, or more generally LMSs) can be adopted for this purpose. An LMS allows instructors to plan, implement, manage, monitor and assess the whole learning process (Alias and Zainuddin 2005), as well as support the administration and communication needs associated with teaching and learning. An LMS may also provide students with the ability to use interactive features, such as threaded discussions, video conferencing, discussion forums, real-time chats and online journal notes (McGill and Klobas 2009). An LMS can be applied to very simple course management systems as well as highly complex, enterprise-wide distributed environments.

Currently, there have been some preliminary attempts to integrate TVET schools and company LMSs (for example, Ocheja et al. 2018). However, an LMS is often thought to be a support for school-based tracks, and it often lacks effective integration with work-based tracks. As a solution, the global market offers LMS platforms aimed at connecting apprenticeships, TVET schools and companies.²² However, there is still scarce evidence of the effectiveness of LMSs. There have been some attempts to design TVET-specific learning environments, allowing stakeholders to better integrate and articulate school- and work-based tracks in the same digital space (see case study 1); however, these do not offer all the features of a traditional LMS.

An LMS includes several tools that can be grouped in three broad categories (Cavus and Zabadi 2014): tools for learners (for communicating, collaborating, working and personalizing learning paths); administration tools (authentication, registration and communication/promotion/offer marketing); and tools for teachers (tracking students, automated testing and course templates). Besides these traditional functions, emerging trends in LMS platforms include the possibility of providing support for virtual immersive reality, MOOCs, digital badges and gamification, adaptive learning systems and learning analytics (Berking and Gallagher 2013).

There are many LMSs on the internet that can be obtained for free (such as Moodle, Claroline and ATutor) or by paying for them (such as Blackboard, WebCT, and others). In the US education market, as of the fall semester of 2018, the top three LMSs by the number of institutions using the were Blackboard, Canvas

20 For more information, see the Pedagogical case: Reuse Library Categories page on the KNORK website.

21 For more information, see the Guide for Combi Oven-Convention Steamer page on the KNORK website

22 For more information, see Open eLMS for Apprenticeships page on the Open eLMS website.

and Moodle (Edutechnica 2018). Worldwide, the picture was different, with Moodle having a market share of more than 50 per cent in Europe, Latin America and Oceania (e-Literate 2017).

With the ever-growing number of LMSs, the task of designing and evaluating them has become even more important. Decision makers need a systematic way to evaluate the quality, efficiency and performance of LMSs to select which one(s) will satisfy the majority or all of one's requirements. One possibility is to automate this evaluation process using computer-aided techniques, which can be especially beneficial for developing countries where a cost-beneficial analysis is even more critical (Cavus 2013). In other cases, institutions could provide suggestions regarding LMS platforms to be adopted for apprenticeship programmes (see box 9).

Box 9. LMS platforms promoted by national authorities

Persona is an LMS that serves organizations with formalized apprenticeship programmes regulated by the US Department of Labor.²³ Persona worked with many unions in the American Federation of Labor and Congress of Industrial Organizations to help formalize their online training ecosystems within their four- or five-year apprenticeship programmes, as well as on their journeymen continuing education series. For example, Persona Learning developed a system for the Boilermakers National Apprenticeship Program in conjunction with the Construction Sector Operations Division of the K-Learning Group.²⁴



²³ For more information, see the LMS eLearning Solutions for Apprenticeship Programs page on the Persona Learning website.

²⁴ For more information, see Boilermakers National Apprenticeship Program launches cutting-edge training program on the Persona Learning website.

► 3.2 Stage 2: Preparing quality training places

After developing a programme (stage 1 of the apprenticeship life cycle), the next stage is to ensure that all its training places have adequate facilities and systems and competent staff as per the training regulations or curricula for a particular occupation or sector. In addition to an enterprise or a TVET centre, training can also take place in intermediary organizations. Therefore, in accordance with the quality assurance process, practitioners should support relevant institutions in preparing training places, which may involve the following processes (see table 1): 1) engaging and registering enterprises to provide apprenticeship training; 2) formulating apprenticeship agreements; 3) building partnerships in apprenticeships programmes; 4) ensuring the capacity of TVET providers to provide the off-the-job component of apprenticeships; or 5) preparing staff to train and mentor apprentices. In the following sections, we will demonstrate how digital technologies could be used to enhance the effectiveness and efficiency of these five main processes.

3.2.1 Registering enterprises through online portals

The registration of enterprises interested in providing apprenticeship opportunities can be automatized to some extent through the adoption of online portals (see box 10 for a few examples). Enterprises often ask themselves whether they are equipped to provide apprenticeship training, and online portals could provide tools to support enterprises in assessing their eligibility to provide apprenticeship training and calculating their return on investment.²⁵ These portals can be used not only to register enterprises but also apprentices, providing a centralized platform to match apprenticeship supply and demand.

Box 10. Online portals for registering enterprises as apprenticeship providers

India has a comprehensive online portal that facilitates the registration of apprentices, enterprises, intermediaries, basic training providers and third-party aggregators.²⁶ The portal captures data in its digital form throughout the life cycle of an apprenticeship – from the registration of an establishment and candidate, to the registration and approval of an apprenticeship contract, the online submission of new courses, and the online payment of stipends and reimbursements. The portal also has a dedicated section for registering grievances from both apprentices and establishments. Enterprises can select apprentices and register apprenticeship agreements through the portal. Apprenticeship candidates and enterprises can access information on available apprenticeship opportunities and applications by parameters such as state, district, sector and trade, organization and qualification. In addition, enterprises can also submit claims for subsidies under national apprenticeship promotion schemes online. Apprentices can also check the results of their final assessment and obtain their e-certificates.

Apprenticeship.gov is an official website of the United States government through which employers or organizations interested in creating or joining an existing apprenticeship programme can express interest.²⁷ The same portal can be used by people interested in enrolling in an apprenticeship program.

²⁵ For more information, see Return on Investment (ROI) on the FASTPORT website.

²⁶ For more information, see the Apprenticeship Training Portal, <https://www.apprenticeshipindia.gov.in/>.

²⁷ For more information, see the Explore Apprenticeship page on the Apprenticeship.gov website.

3.2.2 Formulating apprenticeship agreements through e-signatures and digital signatures

The International Data Corporation (IDC), the premier global provider of market intelligence, forecasted in 2020 that spending on e-signature technology would grow by at least 20 per cent annually over the next five years (Muscolino and Manno 2020). An e-signature is “any letters, characters, or symbols manifested by electronic or similar means and executed or adopted by a party with an intent to authenticate a writing” or “data in electronic form which is attached to or logically associated with other electronic data and which serves as a method of authentication” (Blythe 2005). According to the Connecting Europe Facility (CEF) programme, e-signatures eliminate the need for paper to obtain a signature or seal, removing the time, costs and risks of dealing with paper formats. Depending on national and international regulations, e-signatures provides a guarantee for legal recognition and cross-border interoperability of digital signatures. The importance of e-signature solutions to organizations has become strikingly evident during the COVID-19 pandemic, during which obtaining paper-based signatures was quite challenging. However, the authors’ research shows that e-signatures are still not widespread, especially in apprenticeship programmes, with a few exceptions (see box 11).

Although digital signatures tend to be more secure than traditional paper-based, wet-ink signatures because they are easier to track, especially if generated through a specific digital signature software, there are still many risks that organizations should consider, such as fraud, unauthorized signing and non-compliance with regulations. Adopting e-signatures in the safest possible way requires both technical infrastructure (such as blockchain and anti-fraud systems) and competences, which could explain the current low adoption rates of e-signatures in apprenticeship programmes.

Box 11. E-signatures for apprenticeship agreements

The Queensland Apprenticeship and Traineeship Office in Australia has developed the Electronic Signing Policy for apprenticeships and traineeships in Queensland to provide guidance to relevant stakeholders on validating transactions when in receipt of an electronic or digital signature (e-signature). Paper-based options for all transactions remain an option and will continue to be accepted. However, it is acceptable for communication to occur electronically and for stakeholders to provide and accept an e-signature as an alternate to a handwritten signature.²⁸

3.2.3 Building partnership in apprenticeship programmes through dedicated platforms

In the context of an apprenticeship, an important component of its strategy concerns cooperation among all actors involved in the programme (Eickelmann and Gerick 2018). Stakeholders involved in apprenticeship networks include the following (ILO 2017):

1. Enterprises, which have the main responsibility of implementing apprenticeship training.
2. TVET schools, which offer complementary off-the-job training by developing the capacity of teachers and trainers responsible for the delivery and assessment of apprentices.
3. Local/sectoral coordination services, such as chambers of commerce and industry, chambers of crafts and professional associations, which facilitate cooperation between TVET schools, enterprises and regional administration.

²⁸ For more information, see the Electronic Signing Policy for Apprenticeships and Traineeships in Queensland.

4. Employers' associations and trade unions, which represent the interest of apprentices and workers at the enterprise, local or national levels.
5. Intermediary bodies, which can support SMEs in producing education and training plans, organizing assessment activities, dealing with administrative procedures, and in the case of inter-company training centres, provide training.

TVET schools and enterprises are the two key actors that provide training to apprentices. They have distinct but complementary roles in delivering apprenticeship training. However, some countries have been facing a lack of communication and clarification about the roles and responsibilities of TVET schools and enterprises (British Council 2020). As a result of the separation of these two contexts, apprentices could experience difficulties applying what they learn at school in the workplace and vice versa. Digital technologies could be adopted to support collaborations among TVET teachers, company tutors and trainers for intermediary bodies (see box 12 and case study 1). Digital spaces can also bridge the gap between school and workplace learning contexts in both directions (Schwendimann et al. 2015). From the workplace-to-school context, experiences in the workplace can be used for reflective activities in the school context. From the school-to-workplace context, theoretical knowledge can become more understandable and relevant by connecting it to specific examples of workplace experiences. Bridging the gap in both directions aims to contribute to a deeper understanding of the work processes towards the formation of adaptive expertise.

Box 12. Platforms to support connectivity among apprenticeship learning locations

Realto²⁹ is a platform for integrated vocational education developed within the context of the Swiss project Dual-T.³⁰ The goal of Realto is to bridge apprentice experiences across learning locations by exploiting the combination of mobile devices and an online learning environment. Realto connects, inform and coordinate the stakeholders of an apprenticeship program (such as apprentices, TVET teachers and company tutors) towards the common goal of apprentices' competence development progress. Realto includes two main sections:

- A feed with different kinds of learning activities, which is mainly (but not exclusively) used by TVET teachers to support reflection on apprentices' professional practices (Schwendimann et al. 2015); and
- A workplace-oriented, customizable learning journal (learning documentation), which can be used by both TVET teachers and company tutors to monitor apprentices' competence development.

The learning documentation section is customizable by the needs and specificities of any one profession in Switzerland. Apprentices could include evidence of their learning process collected from activities within the feed in their learning documentations. Realto has been used for different professions, such as clothing designers, to investigate the development of observation skills while exploiting the affordances of its annotation tool (Caruso et al. 2017).

²⁹ For more information, see a video on the Realto platform.

³⁰ For more information, see Leading House Dual-T: Technologies for Vocational Training – CHILI - EPFL



3.2.4 Preparing digitally competent teachers and trainers

TVET teachers as well as company and inter-company trainers play a key role in supporting the development of pivotal skills in apprentices to help navigate an increasingly digitalized job market. As apprenticeship programmes need to adapt to changing skills needs, teachers and trainers must not only update their knowledge and practice, but also exploit new approaches to teaching, such as the use of different kinds of digital technologies (ideally new ones) available in the workplace. This implies that teachers themselves must have strong digital skills and be able to integrate new technologies into their teaching. Therefore, an educational skills framework should include digital competence as a central prerequisite for effective teaching and training.

Digital competence involves more than just knowing how to use devices and applications; it also includes sensible and healthy use of ICT, a balanced attitude towards technology, awareness of the legal and ethical aspects of technology use, privacy, security and a deep understanding of the role of ICT in society and education (Janssen et al. 2013). Therefore, digitally competent educators not only support apprentices in utilizing digital technologies more effectively but also help them understand and develop a critical attitude to the use of technology and its impacts. In addition, TVET teachers and trainers need to consider the evolving nature of technologies, to constantly reflect on their current capabilities and needs, and where necessary, access professional learning and respond to the rapidly changing educational environments and opportunities afforded by emerging technology innovations (Falloon 2020).

Several frameworks have been developed by research and policy institutions to comprehensively describe digital competences required of teachers and trainers.

- The ICT Competency Framework for Teachers developed by UNESCO (Midoro 2013) is intended to be adapted and contextualized to support national and institutional goals. See for example, applications in Tanzania (Mtebe 2020) and Guyana (Moore et al. 2016).
- At the EU level, the DigCompEdu (European Framework of the Digital Competence of Educators, Redecker and Punie 2017) provides a general frame of reference to support the development of educator-specific digital competences in Europe. DigCompEdu is directed towards educators at all levels, including TVET. DigCompEdu is applied at the national level for different purposes, including teacher training (such as in Italy³¹), TVET teacher skills assessment (see Petrovic 2021 for south-eastern European countries; see Rauseo et al. 2021 for Switzerland), and for developing a skills profile for a digital facilitator in an apprenticeship programme (see box 13).

³¹ More information is available in Italian on https://www.miur.gov.it/documents/20182/50615/Brochure_Formare_al_futuro.pdf/78ba8cea-2932-7214-3857-cb40448e93b5?t=1610642503283

Box 13. Use of the DigCompEdu framework to define profiles for digital facilitators within TVET schools

The Cantonal Office for TVET in Ticino (the Italian-speaking canton of Switzerland) committed to the Swiss Federal University for Vocational Education and Training (SFUVET), a research and development project aimed at defining the competence profile of a “digital facilitator,” a person deputed to promote digital transformation within her/his educational institution. SFUVET built the profile by combining different frameworks, including the DigCompEdu and other national frameworks such as the Federal Trainer Diploma (Swiss Federation for Continuing Education).³²

A digital facilitator is described as a professional who, in addition to possessing the teaching skills related to the integration of technologies in the education system, integrates a strong media education competence. In addition, they critically reflect on the specificities of an apprenticeship programme, including articulation and interplay among and across learning sites. The additional skills of a digital facilitator include: a critical attitude towards the digitalization of the job market and vocation profiles; the ability to implement pilot experiments or structural implementations related to integrating digital technologies in educational institutions; and supporting colleagues in the development of their teaching using technologies (Cattaneo, Bonini et al. 2021).

A similar role called a digital animator is presented in Italy. Action 28 of the Digital School National Plan (PNSD)³³ requires every school to have a teacher nominated as a “digital animator”, tasked with a strategic responsibility to promote digital skills across all school levels, including TVET.

Having said that, additional research is required to collect data concerning the effective level of digital competences for TVET teachers. TALIS (2018) managed to collect information from six OECD countries/regions with available data (Alberta [Canada], Denmark, Portugal, Slovenia, Sweden and Turkey) with reference to TVET teachers, which showed that the share of TVET teachers who did not feel prepared to support apprentices using digital technology ranged from 9 per cent in Portugal to 40 per cent in Sweden. Moreover, the type of professional development TVET teachers reported that they needed most was ICT skills training (46 per cent on average across the six OECD countries/regions).

To face these skills gaps, basic and continuing training should be grounded in evidence-based models to support teachers’ and trainers’ digital skills (box 14). Most of the existing research focuses on teacher training instead of company trainers. Tondeur et al. (2012) reviewed the literature, aiming to synthesize strategies on how best to prepare teachers to integrate technology into pedagogy and content areas. They identified the following six strategies:

- acting as role models by providing practical examples of ICT use. Indeed, teachers and trainers should be trained with methods and tools that are like those they would use with their own apprentices (Delfino and Persico 2007);
- discussing and reflecting on the opportunities and risks of ICT use in education (Ching et al. 2016);
- supporting teachers to design ICT materials (Voogt et al. 2013);
- supporting collaboration among teachers (Kuusisaari 2013). Online environments seemed apt for giving teachers a place to discuss and exchange points of view with others, as well as explain their opinions and thoughts (Midoro 2002; Marsh et al. 2010; Sansone et al. 2019);

³² For more information, see the Federal Trainer Diploma page on the Swiss Federation for Adult Learning website.

³³ For more information, see the National Digital School Plan page on the Italian Ministry of Education’s website.

- experiencing the value of using ICT for education in authentic settings; and
- providing ongoing feedback that can be supported in several ways by digital technologies (Lynch et al. 2012).

Box 14. Developing teachers' and trainers' digital skills

The Enhance Digital Teaching Platform,³⁴ developed by the Education and Training Foundation in 2019 and funded by the Department for Education in England, supports teachers in using technology in their classrooms across the further education and training sector. The platform hosts free, bite-sized, certified, online, self-learning training modules that support innovation in teaching and training to improve learners' outcomes. Modules are mapped to the seven elements of the Digital Teaching Professional Framework,³⁵ which promotes, at the national level, a set of professional standards to support learning through technology with the aim of establishing a common understanding of digital skills development.

The Danish government created two knowledge centres for automation and robot technology (north and south³⁶). Each centre provides TVET teachers with teaching materials, such as teaching tutorials or short courses in Industry 4.0, universal robots, collaborative robots and VR applications for teaching and training in apprenticeship programmes. In addition, their specialized facilities provide demonstrations to teachers and students on how robots can be used in the workplace. The centres lend VR headsets and/or robots to TVET teachers, providing them with training materials and face-to-face technical support so that they can operate these technologies and incorporate them into their teaching practice independently. TVET teachers receive continuous support until they are fully able to set up and operate the new equipment. The centres provide these technological resources for TVET programmes in the fields of industrial automation, mechanics, electronics, welding, data and communication, and education.³⁷

3.2.5 Delivering and recognizing the off-the job component of apprenticeship through MOOCs

The off-the-job component of an apprenticeship is crucial to complementing on-the-job training in the workplace by integrating relevant theoretical knowledge with professional practices. Moreover, the off-the-job component usually includes the development of core, digital and entrepreneurial skills as well as, in some cases, practical training, for which enterprises may not have necessary facilities in-house. The off-the-job component is relevant when job seekers are unable to find apprenticeship opportunities or when workplaces are disrupted, such as during the COVID-19 lockdowns (OECD 2020). In some countries, learners can attend apprenticeship programmes with a fully online off-the-job component (see box 15).

34 For more information, see the Enhance website, <https://enhance.etfoundation.co.uk/>

35 For more information, see the Digital Teaching Professional Framework page on the Education and Training Foundation website.

36 For more information, see the CIU website at <https://videnscenterportal.dk/ciu/>.

37 For more information, see the Courses available for all TVET teachers in Denmark page on the CIU website.

Box 15. National apprenticeship programmes that provide 100 per cent online off-the-job components

Openclassrooms is a French project that provides the off-the job component of an apprenticeship programme 100 per cent online. The Openclassrooms platform includes video courses and real-life projects that are always accessible to apprentices. The Openclassrooms apprenticeship programmes include weekly one-on-one mentorship sessions with a dedicated professional in each field for support. Among other subjects, an apprentice can earn bachelor's- and master's-level diplomas in web development, data, IT and project management that are recognized by L'Académie de Paris.

Courses fully delivered online, such as massive open online courses (MOOCs), could be adopted to ensure or complement the off-the-job component of apprenticeship programmes (Stracke 2017) by providing both theoretical and practical knowledge. MOOCs are web-based (online) courses, designed for an unlimited number of participants (massive), conducted by experts in the field (Wulf et al. 2014). MOOCs differ from OERs in that they do not necessarily use open licenses, although they are usually free of charge or impose low participation fees (open). In some cases, MOOCs are built by re-adapting different kinds of OERs (Poce et al. 2020). Two major categories of MOOCs can be distinguished based on their pedagogical design (courses):

- **Connectivist MOOCs (cMOOCs):** These are MOOCs based on connectivism as the learning theory. They encourage discussions, social network engagement and the construction and sharing of content and creativity.
- **Extended MOOCs (xMOOCs):** These are MOOCs based on the traditional behavioural-cognitivist ideas of knowledge transfer. xMOOCs mainly use lecture videos, quizzes, short tests and supplemental written materials.

Although MOOCs are historically related to higher education, today, a growing number of MOOC applications are concerned with workplace settings (Egloffstein 2018).

For instance, Udacity, with approximately 4 million users, has shifted its business model towards professional education (Ifenthaler and Schumacher 2016) and has recently launched a blended learning initiative, combining off-the-job learning with on-site training. Udacity is partnering with companies to develop content and build in-house courses (box 16). Similarly, Coursera, beginning in the higher education market, has recently integrated with the corporate market for various business offerings.

Box 16. Partnerships between MOOCs and companies to provide training in digital competences to employees

Royal Dutch Shell in the United States and other countries is reskilling their workers in programming and machine learning while partnering with Udacity, one of the biggest MOOC providers in the country. These strategies were put in place before the COVID-19 pandemic, but they were accelerated as an effect of the crisis. As reported by CNBC, Royal Dutch Shell focuses on getting its workforce skilled in AI as they move to develop alternative sources of energy.

The potential to complement on-the-job learning is demonstrated by the number of part-time or full-time adult employees who attend MOOCs (Pickering and Swinnerton 2017) without necessarily being solicited by their employers (Castano et al. 2017). Employees attend MOOCs to gain specific skills to do their jobs better (Christensen et al. 2013), fill gaps in formal knowledge, prepare for new roles and career progression (Milligan and Littlejohn 2017), and improve their current job situation or find a new one (Zhenghao et al. 2015). Recently, MOOCs have also integrated micro-learning strategies that allow apprentices to personalize their learning path by choosing specific content/activities in a MOOC based on their learning needs (Buchem and Hamelmann 2010).

Data from various studies show that online courses like MOOCs are usually attended by relatively well-educated males within the age group 25–54 years (Kato et al. 2020). These results are in line with PIAAC data showing that participation in non-formal education and training is usually undertaken by people with higher levels of education and skills (OECD 2019). Research also shows that MOOCs require learners to have a high level of self-regulating skills. However, learners often struggle to self-regulate their learning in MOOCs (Jansen et al. 2020), which can be particularly challenging for learners with lower levels of education. This issue is connected to another huge weakness of MOOCs: the high rate of learners dropping out. The literature has identified different factors related to MOOC drop outs, which can be classified into interrelated categories: 1) course design (Colman 2013), which includes little interaction with other learners and instructors, too little personalization of instruction (Gütl et al. 2014) and course length (Jordan 2015). 2) learners' personal attributes, which include motivational aspects and a lack of self-regulated skills (Pérez-Álvarez et al. 2018). Having said that, research shows that providing self-regulated learning instructions and study suggestions through video within MOOCs positively affect learners' course completion, metacognitive activities and proactive behaviours (Jansen et al. 2020). Some programmes manage to design courses that can attract non-traditional MOOC learners such as TVETers, refugees and learners from low-income backgrounds (Fain 2018; Burke 2019).

In line with the disadvantages already mentioned for OERs, the well-recognized MOOCs provide content exclusively in English, with educational resources based on specific cultural contexts. To overcome these issues, some countries have developed national MOOCs (see box 17). The case presented in box 14 shows how MOOCs have the potential to offer skills courses for millions of people at a relatively low cost (Gaba and Mishra 2016), which is particularly beneficial for countries aiming to increase their number of skilled citizens.

Box 17. MOOCs as a tool to increase the number of skilled human resources in India

The Indian government initiated the development of a national platform for MOOCs called Study Webs of Active Learning for Young Aspiring Minds (SWAYAM) to achieve its goal of 550 million skilled workers by 2022. The platform is designed to host 2,000 courses and 80,000 hours of learning, covering secondary school, undergraduate studies, postgraduate studies, engineering, law and other professional courses. The University Grants Commission (UGC) released a regulatory framework for MOOCs, providing up to 20 per cent of the total course credits being offered in a particular programme in a semester through online learning courses offered through the SWAYAM platform. The platform will cover curriculum-based courses in higher education, school education (grades 9–12), skill courses and courses for lifelong learning.

► 3.3 Stage 3: Organizing apprenticeship training

Having established the basic conditions for an apprenticeship programme (stage 2 of the apprenticeship life cycle), the next step is to organize and deliver the apprenticeship training. To deliver the training effectively, it is important to support apprentices through the programme and monitor their progress. This stage is usually organized in six processes (see table 1): 1) attracting candidates to participate in apprenticeship training; 2) recruiting apprentices; 3) developing a training plan; 4) implementing effective training delivery methods; 5) monitoring, assessing and certifying qualifications; and 6) ensuring social inclusion. In the following section, we will show how digital technologies can be used to enhance the effectiveness and efficiency of these six main processes.

3.3.1 Attracting candidates to join apprenticeship training through video-based technologies

Increasing the attractiveness of work-based learning schemes, such as TVET and apprenticeships, has been a priority for many countries, primarily for economic and social development reasons. The average participation in work-based learning in the EU is still below the target of 15 per cent, with considerably higher rates in Denmark, Finland, Sweden, Germany and Austria (CEDEFOP 2018). Apprenticeship programmes are often perceived to be linked to blue collar jobs, offering low wages and operating mainly in male-dominated sectors (Atkins and Flint 2015). Moreover, they are considered inferior to academic programmes in terms of employability and status (Chankseliani et al. 2016), and this is particularly true in liberal market economies compared to those that are more coordinated, such as Denmark or Germany (Bosch and Charest 2008). The ‘unattractiveness’ of work-based learning is experienced by both developed and developing countries. In many Asian countries, including China, India, South Korea, and Russia, parents who can afford it rarely support their child in choosing a vocational path (Ratnata 2013). Thus, many countries are considering strategies to promote a higher awareness of the opportunities provided by workplace learning paths (see box 18).

Box 18. Online courses on promoting apprenticeships in Europe

The European Alliance for Apprenticeships (EAfA) has launched an online training module on making apprenticeships a first choice for young learners, adults, and underrepresented learners. The new module falls within the first EAfA priority of focusing on high-quality and effective apprenticeships, and it covers some of the transversal issues EAfA is also keen to address, namely social inclusion and gender balance.³⁸

Digital technologies can be used to help potential apprentices develop a more realistic understanding of the opportunities provided by apprenticeship programmes by:

- Attending webinars with employers to gain first-hand knowledge of what employability entails (Chatterton and Rebbeck 2015).
- Watching videos where former apprentices tell their educational and career stories.
- Actively exploring their future workplaces through VR and 360-degree video experiences (Assilmia et al. 2017; Spangenberger and Freytag 2020).

³⁸ For more information, see the Employment, Social Affairs & Inclusion page on the European Commission website

Box 19 presents various examples of videos and visualization (from more traditional videos to 360-degree videos and video conferencing tools) adopted to promote work-based learning programmes for potential apprentices.

Box 19. From traditional videos to immersive 360-degree videos to improve apprenticeship attractiveness

The Bridge to Work³⁹ initiative helps potential apprentices gain insight into employers' expectations before they apply for apprenticeships in the United Kingdom. The team sets up a series of webinars using video conferencing software to bring students and employers in local and national firms together. Through the webinars, students gain first-hand knowledge of what employability entails and develop the confidence and skills to talk to employers.

"Film your job?" is a digital video platform aimed at promoting apprenticeships by introducing young people to apprenticeships and trades through short videos. The platform hosts videos created by apprentices who film themselves at their workplaces. Apprentices create those videos as part of a contest organized in France every year.⁴⁰

The Valais Association of Master Builders (Switzerland) and the HES-SO Valais-Wallis University of Applied Sciences are using immersion and VR to combat the lack of young talent in the construction industry. With VR glasses, young people can immerse themselves in the day-to-day work of various construction professions, choosing from more than a dozen 360-degree videos. These videos were conceived and filmed in collaboration with the professional associations involved in the Valais Canton. The films show various typical work situations of a particular profession. One of the videos begins in a metal construction workshop, where workers cut and weld metal components.⁴¹

A similar project called "Your first day" shoots 360-degree videos about various professions and makes them available to all interested schools in Germany, free of charge and with all the necessary technology to view them. Since 2018, class sets of immersive 360-degree videos have been available free to German schools with the aim of facilitating career-orientation goals. This resource can help young people find out more about career paths and companies that they would not otherwise have access to. It also offers companies the opportunity to digitally open the doors of their production facility, office or business premises and introduce themselves to future professionals.⁴²

In addition, Roche,⁴³ a leading German biotech firm, started to use virtual tours because the COVID-19 pandemic did not allow for in-person fairs or events to be held. With the help of live chats or video meetings, personal contact can be established with fair visitors. Apprenticeship seekers can move digitally through an event hall, visit a booth of their choice and obtain information they need on-demand and at any time. Such a virtual tour uses real images of the building or site so the visitor has the feeling of being present.



39 For more information, see the Bridge to Work page on the City Bridge Trust website.

40 For more information, see the Film Your Job website, <https://www.filmetonjob.com/>.

41 For more information, see the article "Discover real construction professions in the virtual house".

42 For more information, see the web page of the project "Your First Day"

43 For more information, see the Roche Diagnostics website, <https://www.roche.ch/en/standorte/basel-hq/virtual-tour.htm>.

3.3.2 Enabling recruitment using artificial intelligence and blockchain

The recruitment process has been largely disrupted by the advent of the internet and digital technologies. Gigauro et al. (2020) distinguished three phases of digital recruitment technologies.

1. Digital Recruitment 1.0 is based on digital job boards. These platforms allowed companies, for the first time, in the mid-to-late 1990s to reach out many potential employees on a lower budget. Simultaneously, applicants could look for and screen job advertisements easily. Currently, national and international institutions have been implementing public job boards to support the match between potential apprentices, companies and TVET providers.
2. Digital Recruitment 2.0 is based on two kinds of technologies:
 - Platforms that automatically aggregate jobs across multiple individual job boards so that candidates can find all open positions in one place. This technology was particularly relevant because of the proliferation of job boards in Digital Recruitment 1.0.
 - Digital professional and social network platforms, such as LinkedIn (launched in 2003), that allow firms to post job opportunities efficiently and to target job ads and opportunities to prospective job candidates.
3. Digital Recruitment 3.0 is based mainly on AI, which enables filtering applications to contact candidates for the first round of interviews through chatbots as well as conduct digital job interviews (van Esch et al. 2019).

One example of an AI technique commonly used in recruitment is data mining, which can be defined as extracting valid, previously unknown, comprehensible and actionable information from large databases through an automatic or semi-automatic method and using it to make decisions (Geetha and Bhanu 2018). Chien and Chen (2008) proposed a framework for a data mining system based on the decision-tree technique, which is often used for classification and prediction when screening an enormous number of resumes. The proposed system was created with demographic data such as age, gender, marital status, education and experience to predict applicants' future performance and retention. These techniques can help recruiters automatize routine and fatiguing tasks, such as CV screening. This is particularly relevant due to an increase in the number of candidates (those who not always in line with the job description requirements), which was an unintended effect of the Digital Recruitment 1.0 and 2.0 phases.

Despite the potential advantages of AI-enabled recruiting tools, there are also several limitations that decision makers need to consider (Black and van Esch 2020) including:

1. The cost of creating AI-enabled recruiting tools and systems. SME could rely on external providers rather than invest in their own systems. Even though AI tools are not free, they are estimated to be cost-effective for candidate pools that are larger than 200 people (Black and Gregersen 2013);
2. Privacy and ethical issues, as well as legal restrictions, concerning the use of personal data (Canhoto and Clear 2020);
3. AI selecting information based on algorithms designed by people. Existing biases, which often characterizes selection processes (such as age, gender, or race), are at the risk of being maintained and even reinforced by the adoption of AI systems (Williamson 2016);
4. The recruiters' attitudes toward AI-enabled recruiting tools. Whether recruiters in human resources see AI as a threat or opportunity will likely depend on whether it is applied as a complement or substitute.

All these challenges need to be considered since many companies have already integrated AI systems in their recruiting processes.

One of the technologies that seem solve, at least in part, the issue of job seeker privacy is blockchain. A blockchain-based digital ID is a decentralized ledger of identity. All the digital attributes and activities of a person are stored automatically on a blockchain platform, and information stored in this decentralized ledger will remain with immutability, transparency and traceability as a reliable database for recruiters to rely on when making hiring decisions (AkaChain 2020). This means that apprentices' individual data, such as education, employment history, references and credentials (such as badges, see section 2.3) are associated with a verified ID.

Until now, blockchain technology has been used by educational institutions to manage student records for examinations, the verification of answers, maintaining record integrity, security and consistency (Sharples and Domingue 2016; Hoy 2017). Ocheja and colleagues (2018) proposed the application of a blockchain technology that integrates data from an LMS (see section 2.5) to be used by educational institutions, organizations and industry to achieve a centralized knowledge repository. Similarly, Liu and colleagues (2018) implemented a blockchain system where students can easily share their educational recordings with employers. This blockchain system is aimed at reducing the information asymmetry which usually characterizes cooperation between education–industry cooperation, especially regarding an apprentice's learning path and competences. Although blockchain technology is still in the early stages, it has the potential to guarantee more ethical recruitment practices (Christ and Helliard 2021). Blockchain has been already developed as a solution in both developed and developing countries as it has the potential to reduce the costs related to certified paper-based credentials and diplomas (see box 20).⁴⁴ According to the OECD (2021), with growing momentum among technologists and policymakers to return the control of personal data to users, an international standards movement has arisen to ensure that blockchain systems are used in a manner that protects user privacy by being independent of any vendor infrastructure (OECD 2021).

Box 20. Blockchain application in apprenticeship and professional programmes

In Egypt, the Zewail City of Science and Technology signed an agreement with the start-up Intelli Coders to build BlockCred, a blockchain-based platform for universities, companies and non-academic institutions to issue and manage academic credentials. The platform offers a blockchain ledger to store and manage academic credentials. Employers can request, verify and share employee credentials through the distributed ledger.⁴⁵

In order to comply with the provisions issued by both federal and state health authorities, which include avoiding crowds due to the COVID-19 emergency, the State Directorate of Professions (DEP) in Colombia had invited professionals in the state who, for whatever reason, still do not have their apprenticeship license to obtain it through an online procedure. The DEP has been providing this online service using a blockchain technology called Xertify since September 2019.⁴⁶

⁴⁴ For more information, see Xertify as a Social Innovation on medium.com.

⁴⁵ For more information, see the Blockcred page on the Tracxn website.

⁴⁶ For more information, see La Fuente website, <https://periodicolafuente.com/profesionistas-tramitar-cedula-en-linea/#>



3.3.3 Developing a training plan through project management tools

The training plan developed by an enterprise determines how it implements its apprenticeship curriculum in the workplace. The enterprise training plan should provide a complete description of the training to be delivered and the competencies to be developed. More specifically, the training plan should set out when and where different training sequences will be carried out and identify the individuals responsible for delivering the training. It should also specify how and when assessments will take place. Corresponding to the enterprise training plan, TVET providers should also prepare a plan for off-the-job training that complements on-the-job training at the enterprise. The combination of on- and off-the-job training guarantees that apprentices are work-ready upon the completion of the programme. Project management platforms could be used to track apprenticeship programmes, making them transparent among different learning venues (see box 21).

Box 21. Tracking apprenticeship programmes

The ApprenticeTrack⁴⁷ app provides a platform to track apprenticeship programmes. It serves as a central repository for all documents regarding an apprenticeship and simplifies the administrative workflow before the apprenticeship takes place. All parties (the students, mentors, professors/apprenticeship organizers and school administrators) can access and modify these documents. The application can be integrated with already existing school information systems or work in standalone mode. The ApprenticeTrack app was funded by the European Commission and tested in Croatia, Slovenia and Czech Republic.

BC Crane Safety in the United States provides its apprentices with a mobile logbook called SkillRecord,⁴⁸ which allows users to log hours worked, tasks performed, and equipment used, with the option of easily adding photographs to the entries. It automatically summarizes logbook entries by employer, equipment, and other criteria, providing a broader, more complete picture of apprentices' experience and skills. Finally, SkillRecord also allows apprentices to view their logbooks, thereby facilitating collaboration and peer-to-peer learning.

⁴⁷ For more information, see the Apprentice Track website, <https://apprenticetrack.eu/>.

⁴⁸ For more information, see the Operator Logbook page on the BC Crane Safety website.

3.3.4 Effective training methods

Over the last few years, scientific literature in learning and cognitive sciences has highlighted the importance of shifting from traditional/transmissive teaching methods to instructional strategies that support interaction and the collaborative construction of knowledge objects and practices (Paavola et al. 2004; Chi and Wylie 2014; Kimmons et al. 2020), with a strong emphasis on guiding the student's learning process (Kirschner et al. 2006). This development in learning theories was shaped in parallel to the growth of digital technologies.

With the advent of the internet, learners and teachers started to deal with a measureless increase in information and resources, which made them aware of an "open-ended world" behind all the topics and subjects. Therefore, the expert (or the textbook) might no longer be considered the repository of all knowledge and wisdom to be "transferred" to the learners. In contrast, several digital technology affordances (Bower 2008; Cattaneo et al. 2015; Aprea and Cattaneo 2019), such as ubiquity, multimodality and interactivity provided opportunities to transform educational practices, giving learners a more active role through their interactions with the educational materials, their collaborations with peers and instructors, and from the construction of digital knowledge artefacts (Scardamalia and Bereiter 1994).

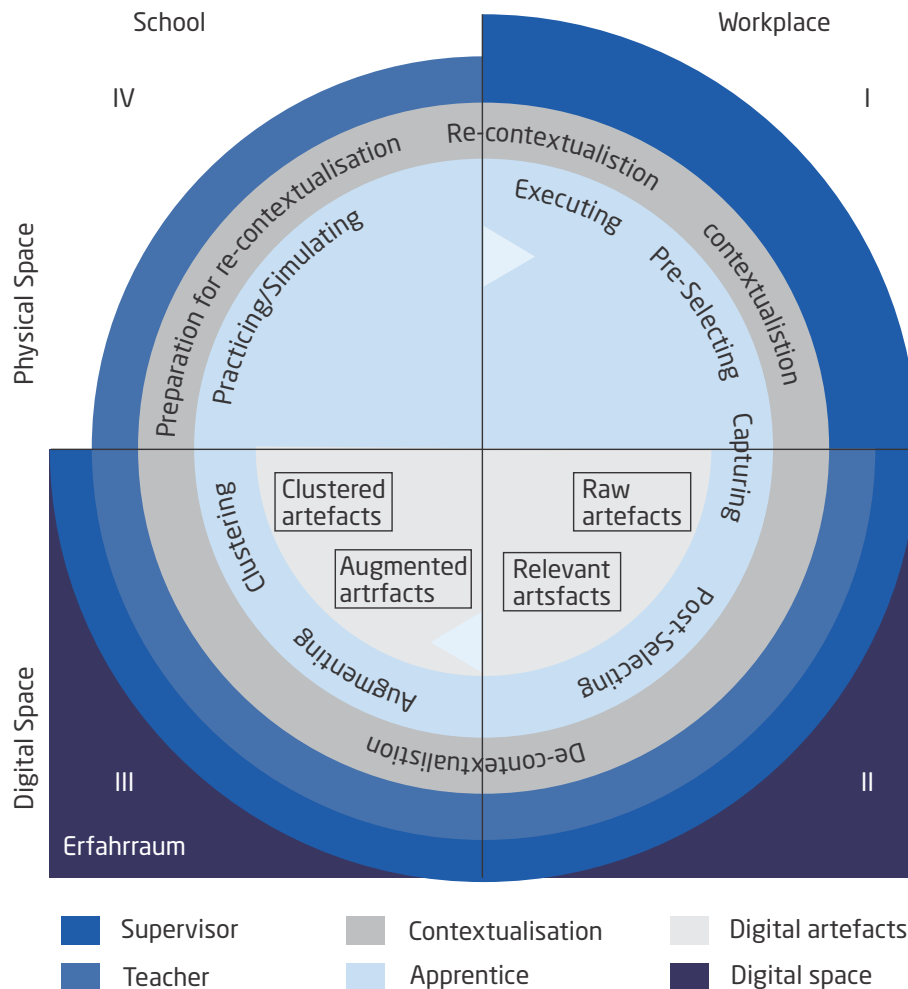
This broader trend in learning sciences also affected the development of educational models for TVET and apprenticeship programmes. Apprenticeships are a peculiar learning laboratory because they require learners to constantly deal with different kinds of knowledge and practices, both from more formal contexts (such as TVET schools) and professional contexts. However, researchers have shown that when "crossing the borders" between learning environments, apprentices can perceive discontinuities and, consequently, struggle to connect what they learn in formal and professional learning contexts (Berglund and Henning Loeb 2013; Kilbrink and Bjurulf 2013). Despite these challenges, the perceived contradictions between knowledge, practices and values are worth facing as they can be vital forces for change, learning and development (Illeris 2011; Engeström 2015).

Several research studies have investigated how to create spaces for reflective practices in TVET educational systems with the support of digital technologies. On these bases, for example, the *Erfahrungsraum* model was developed (Schwendimann et al. 2015). This model is a technology-enhanced pedagogical model that supports students' learning at the borders across vocational learning locations. According to the model, when adequately exploited, technologies can provide a specific space to reflect upon apprentices' professional experiences, thus supporting learning and professional development.

The *Erfahrungsraum* model distinguishes four sequential phases ('quadrants'), but the point of departure can vary (see figure 3). On the vertical axis, it distinguishes between physical and digital spaces of learning, and on the horizontal axis, between formal education and workplace contexts. The rings distinguish between the role of supervisors/company trainers (red ring/outermost circle), the role of TVET teachers (blue ring/second circle), the synthesis between theoretical and procedural knowledge (green ring/third circle), apprentices' actions (yellow ring/fourth circle), and digital artefacts (orange half-circle/innermost circle). The digital *Erfahrungsraum* space is represented by the grey box enclosing quadrants II and III, which allows stakeholders to cross the borders of one's own learning location while also inhabiting the other location, thus facilitating the articulation of learning experiences across school- and work-based contexts.

In the following sections, we will show illustrative and non-exhaustive examples of how digital technologies can be exploited to iteratively execute tasks, reflect on them and re-execute tasks and procedures across different learning locations.

Figure 3. The Erfahrerraum model



Source: Schwendimann et al. (2015).

3.3.4.1 Executing procedures and tasks at the workplace with the support of AR

The focus of activity in the workplace is on executing given procedures. AR has been shown to be particularly effective in supporting and scaffolding procedures within real workplaces, included but not limited to carpentry (Lee et al., 2019), maintenance (Palmarini et al. 2018), assembly (Wang et al. 2016), nursing (Wüller et al. 2019) and agriculture (Xi et al. 2018). See box 22 for examples.

AR overlays the physical world with virtual content to create an immersive platform that places the trainee in a real-world context, engaging all their senses (Bacca Acosta et al. 2014). AR applications can be classified on two main features (for other possible classifications, see also Elia et al. 2016; Edwards-Stewart et al. 2016):

- A kind of device that allows the user to visualize the virtual content. While some devices, such as smartphones, need to be held by the user (handheld), others, such as goggles, do not (handsfree). The former category makes the AR experience more accessible since currently, approximately half of the world's total population owns a smartphone device (Statista 2021). However, the latter category, which includes AR smart glasses, seems to be the most promising option for workplace learning because apprentices could manipulate objects and execute tasks without any constriction. Smart glasses like Microsoft HoloLens⁴⁹ are currently quite expensive, which is one of the reasons why this solution has not been widely adopted in apprenticeship programmes.
- An input needed to activate the virtual content; some rely on markers (marker-based), such as a barcode or QR code placed in the physical environment that are captured by a camera, thus creating an AR experience (Brito and Stoyanova 2018). Marker-less devices place virtual 3D objects in the real, physical environment, depending on the environment's real features rather than identifying markers.

Modern AR systems can communicate with various sensors (such as cameras, pressure sensors and eye trackers) in real time, which can offer an even broader range of training affordances (Limbu et al. 2019). Sensor-based AR training environments can support apprentices by providing personalized guidance and feedback when company tutors are unavailable or during remote assistance (Schneider et al. 2010; Limbu et al. 2018). Research on AR has revealed that there are still some possible barriers to its adoption (Garzón et al. 2019). Trainers participating in some studies manifested having technical difficulties when using AR in their classrooms. This may be caused by limited technical training in managing the AR systems on the part of some trainers, which could limit their use in learning environments. Moreover, resistance from teachers has been reported as a possible difficulty in implementing AR in educational environments.

Another reported issue related to AR systems is multitasking. AR could demand too much attention from learners, causing cognitive load. This issue could be exacerbated by technical issues during use, which researchers have already reported as one of the limitations of the current applications of AR in educational settings (Akçayır and Akçayır 2017). Thus, it has become apparent that in order to introduce AR into an apprenticeship, it is necessary to: 1) design user-friendly technical solutions by paying adequate attention to the user experience; 2) train teachers and trainers to adopt AR solutions for professional learning; and 3) develop pedagogical design principles for the effective use of AR in professional learning.

Box 22. Applications of AR in workplace learning

A marker-based AR application called HardwareAR was developed to teach Turkish undergraduate students in a computer hardware course how to assemble a motherboard. The use of AR had a positive impact on student achievement in motherboard assembly and helped the learners complete the assembly process in a shorter time and with less support (Sirakaya and Kilic Cakmak 2018).

The COSMO (Cognitive Support in Manufacturing Operations: Cognitive guidance in production) project designed, developed and evaluated effective, personalized and scalable AR technologies for support and training in manufacturing operations in Belgium.⁵⁰

EON Reality has created a marker-based handheld AR application called LKDF Interact for Volvo's Selam Vocational Training Centre in Ethiopia. This app teaches the basics of diesel engine maintenance

⁴⁹ For more information, see the HoloLens page on the Microsoft website.

⁵⁰ For more information, see the COSMO page on the imec website.

through hands-on learning using a gamified AR experience. By letting the learner experience the subject, AR learning overcomes literacy and language barriers by directly showing rather than telling.⁵¹

A marker-based handheld mobile AR application named Paint-cAR was developed to support the learning process of how to repair the paint on a car in the context of a vocational education programme for car maintenance in Spain. Repairing the paint on a car is a complex process that involves a sequence of 30 steps and the use of many chemical products and tools. According to the teachers, the apprentices gained experience in paying attention to and memorizing the procedure using this application. The results of a preliminary experimentation revealed that the apprentices exhibited increased attention during the procedure, and they felt more confident while executing it (Bacca Acosta et al. 2015).

Developed by Purdue University in the United States with support from the National Science Foundation through a US\$5 million cooperative agreement, Skill-XR is a prototype system to provide workplace training using AR.⁵² The “X” in Skill-XR includes a range of technologies, including AR, VR and extended reality (XR). As an example on the Purdue University augmented reality website explains, a newly hired factory apprentice may wear AR glasses while being trained on a piece of equipment and see graphics overlaid on the machine about how to operate the controls. Instant feedback while performing the task correctly ensures that workers are trained quickly, effectively and safely. Most AR experiences involve complex programming and other specialized skills that companies do not have and cannot afford to purchase. The goal of the Skill-XR project is to enable anyone to generate an AR experience, whether it is in a factory, classroom or their own home. It is also designed to be platform-agnostic, implementable in new devices or in mixed-reality technologies available in the marketplace.⁵³

In immersive AR scenarios, sensors worn on the body can be used to capture, analyse and replay human performance for training purposes. The WEKIT solution includes a hardware and software application that complements AR glasses with a wearable sensor-actuator experience.⁵⁴

The WEKIT solution was tested in three professions: aircraft maintenance (Norway), medical imaging (Italy) and astronaut training (Italy). It is built for the Microsoft HoloLens, an AR platform. The application consists of two main interfaces: the recorder interface (for the company tutor/expert) and the player interface (for the apprentice).

The recorder interface supports experts in creating learning content using two main functionalities: the annotation of objects and locations in the physical space. Company tutors/experts can enrich the physical space with virtual images, point-of-view videos, voice recordings, place 3D models, mark a physical location as a point of interest and record sensor data. Smart glasses worn by the experts generate a spatial map of the environment to attach all augmented content relative to physical anchor points. Specifically, the expert can create “task stations” by pointing a gaze cursor to the desired location. Task stations and their attached virtual content are then subsequently translated to a linear or branched sequence of action steps to be used in the player interface. The captured learning activities can then be uploaded to a cloud repository when complete.

51 For more information, see the AR Training: Engine Maintenance page on the Eon Reality website.

52 For more information, see the Using Skill-XR to Upskill Workers video by Working Nation.

53 For more information, see Augmented reality to provide new skills for manufacturing workforce education on the Purdue University website.

54 For more information, see the WEKIT ECS website, <https://wekit-ecs.com/>.

The player interface allows trainees to learn from expert-created learning content, and students can download a learning activity from the cloud. Once downloaded, the player interface generates the user interface as a task list and task cards for stepwise guidance. The player interface projects the augmentations at the right location and in the right sequence. Students can navigate between the steps using voice commands or gestures.

Research has showed that the captured expert models were positively received in all three domains, and the identified level of acceptance suggests that the solution is capable of capturing models for training purposes at large (Limbu et al. 2019).

3.3.4.2 Reflection-on-action through digitally enhanced writing

Reflection is essential for professional competence development in every profession (Cattaneo and Motta 2020). Reflection-on-action (taking place when a task is already accomplished) and reflection-in-action (occurring while performing the task) are equally important to increasing one's professionalism (Schön 1983). Especially, TVET teachers and inter-company trainers can support apprentices' reflections on professional practices at work by connecting implicit and procedural knowledge with theoretical knowledge. Reflective writing-to-learn is an effective strategy to stimulate professional competences as well as deep learning (Mauroux et al. 2016; Ortoleva and Bétrancourt 2016). Note taking specifically enhances reorganization, elaboration and recall, and it enables the learner to better connect the new information with prior knowledge (Delen et al. 2014; Mu 2010). Further, it supports analysis and reflexivity (Colasante 2011; Rich and Hannafin 2010; Tripp and Rich 2012).

Video annotation (Evi-Colombo et al. 2020) tools are examples of how technology can enhance reflective writing. Video annotation is a feature provided by some hypervideo⁵⁵ platforms (Sauli et al. 2018), which can provide two different kinds of annotation:

- Individual video annotation, which allows integrating notes into video-based artefacts while watching the video (Colasante 2011). Some hypervideo platforms allow for generating a PDF file, which gathers all the notes taken with the frames they correspond to (Cattaneo et al. 2015).
- Collaborative video annotation, which allows multiple users to annotate the same video (Hulsman and van der Vloodt 2015) or to share the annotations in a group learning environment with online sessions or blog-like interfaces.

Video annotation could facilitate individual reflection on real or simulated workplace practices (Cattaneo et al. 2015) and teach users what elements of practices are important or controversial, as well as add theoretical knowledge to workplace experiences (Perini et al. 2019).

Apprentices can capture relevant and personal experience at work, such as filming themselves during a professional practice. The material collected at work can be used to activate a reflection, both within authentic professional contexts and simulated professional contexts at school (see box 23)

⁵⁵ A hypervideo can be defined as a non-linear video that presents both classical (such as play, pause, stop and rewind/forward buttons) and more complex (for example, a table of contents and index) functions to control the navigation of the video stream, and it is enriched with hyperlinks providing access to additional material (documents, audio files, images etc.) through markers or hotspots (Sauli et al. 2018). A hypervideo can also be provided with a variety of exchange options, which include individual and collaborative video annotation. Finally, hypervideos allow users to receive feedback through the specified communication tools or automatically from the system (for example, through a quiz feature).

Box 23. Using video-annotation in hyper-videos to support reflection on professional practices

In Switzerland, videos, and specifically hypervideos, are used to stimulate reflection on professional practices. These videos can be used to record apprentices' relevant procedures (such as the most difficult, the most important while performing a specific task, or the most different depending on the typology of workplace setting). Depending on the context, a real or simulated procedure can be recorded. The rough video material can be imported to iVideo.education,⁵⁶ a digital platform specifically designed to turn simple videos into hypervideos for professional training purposes (Sauli et al., 2018). For example, iVideo allows trainers to highlight critical incidents within a video-recorded professional practice (by introducing simple animations such as active points) to stimulate apprentice reflection.

Moreover, apprentices and the teachers can insert comments in specific video time frames (called video annotations), which can support apprentices' self-reflection on one side and more detailed and focused feedback from supervisors on the other (Evi-Colombo et al. 2020; Cattaneo et al. 2020). In the context of nursing education, for example, an actual surgery during which apprentices worked was recorded to be used as a material for a face-to-face, focused and contextualized debriefing between the apprentice and their hospital supervisors.

In other nursing educational settings, the recording of a simulated procedure of inserting a urinary catheter was turned into a hypervideo by the apprentices themselves, who worked in small groups to turn the rough video into an educational hypervideo. Specifically, they were required to design the hypervideo as a learning resource for their peers. This activity produced a positive effect on the acquisition of theoretical knowledge as compared to a traditional classroom lesson on urinary catheter insertion (Evi-Colombo 2020). The use of this hypervideo solution has been the object of several learning activities in different domains, always proving to be effective for learning and motivation outcomes (for example, Cattaneo et al. 2016, 2018, 2019; Cattaneo and Sauli 2017).

Table 3 describes an instructional scenario using video annotation within the context of a commercial employee apprenticeship programme (Ghisla et al. 2014). Research has shown that procedural learning benefits from the detection and written analysis of errors through the support of video annotation (Cattaneo and Boldrini 2017).

Table 3. Using video annotation in a commercial employee apprenticeship programme (Switzerland)

Phases	Activities
1. Capturing relevant professional experience	Apprentices' video recorded themselves during consultancy interviews at work.
2. Reflecting	A group of apprentices watch the video in the classroom and video annotate their observations. Each group presents their collected observations to the class.
3) Connecting professional and theoretical knowledge	Based on the apprentices' reflections, the trainer elaborates an overall and generalizable analysis of the situation of handling a counselling interview. The trainer shows a video of a counselling interview managed by an experienced salesman to "fix" the theoretical elements presented.
4) Simulation before returning to work	The trainees are asked, in pairs, to conduct and videotape a consulting interview in the classroom (simulation). Each video produced is then viewed by another pair of apprentices who provide feedback through video annotation.

Source: Adapted by the authors from Ghisla et al (2014).

⁵⁶ For more information, see the iVideo.education presentation.

3.3.4.3 Simulating professional experiences outside of workplaces

Practicing exercises or simulations outside of the workplace (for example, in intercompany courses and TVET schools) is an important component of an apprenticeship program. Simulations can make theoretical knowledge more relevant and help apprentices make sense of practical situations in the workplace. Moreover, they can reduce the chances of damaging company materials and injury in the workplace (Carruth 2017).

Simulations outside the workplace can be carried out in:

- A physical space through the support of digital technologies. For example, apprentices can simulate, video record and analyse a consultancy interview in class (see table 3).
- A virtual environment, which can be accessed through a screen (such as a computer desktop, tablet or smartphone; see Hämäläinen and Cattaneo 2015) or through head-mounted displays (immersive VR).

More and more often, virtual prototypes of workplaces are adopted as innovative training solutions. Virtual prototypes allow apprentices to investigate different possible situations (Grajewski et al. 2015; Dobricki et al. 2021; see box 25) and to recreate low-frequency, dangerous or expensive events as many times as needed, such as training for first responders (Mossel, Froeschl et al. 2017) or training for chemical, biological, radiological and nuclear operations (Mossel, Peer et al. 2017). VR can also be used with limited supervision (Limbu et al. 2018), allowing apprentices to access training at their convenience, without needing a trainer to provide constant supervision. In some cases, VR experiences can be integrated within an LMS (Palkova and Hatzilygeroudis 2019; see box 24).

Box 24. Integrating VR learning experience within an LMS

The AVARES⁵⁷ project integrates a developed virtual world with a traditional LMS, represented by Moodle, for more attractive learning in the challenging field of renewable energy sources. The hybrid educational platform developed by the AVARES project combines traditional online learning procedures offered to European students via Moodle, acting as a virtual learning environment, with learning procedures delivered to students in a 3D virtual world. The virtual world is developed in Open Simulator (OpenSim), an open-source platform for creating multi-user 3D virtual worlds. The virtual learning environment focuses on the management of the learning material processes, whereas the virtual world environment offers students the ability to interact and experiment with items and constructs in a way similar to the real world. The project involves six European countries: Greece, Slovakia, Germany, Portugal, Romania, and Lithuania.

Immersive 3D VR environments have consistently been found to facilitate the work-related experiential learning of apprentices, outperforming desktop or table VR experiences in terms of motivation and learning outcomes (Bharathi and Tucker 2015), owing to a higher sense of presence in the immersive VR experience (Max and Sarah 2016).

The immersive 3D VR experience can be further enhanced in different ways by:

- introducing gamification elements to the experience (Checa and Bustillo 2020);
- integrating the immersive VR experience with sensorial feedback, for example, by using haptic simulators (Grajewski et al. 2015; see also case study 2);
- integrating virtual agents to provide feedback during the immersive experience (Zhao and Ma 2021).

⁵⁷ For more information, see Palkova, Zuzana et al., "Enhance attractiveness of renewable energy training by information technologies and virtual reality".

Box 25. VR application for simulating professional practices training

GardenVR⁵⁸ is an immersive 3D VR experience that allows apprentices to practice and develop their skills by designing a garden and exploring it in an immersive environment. GardenVR was designed according to three design principles:

- **Multiple perspectives:** Apprentices can experience two main perspectives called the design mode and the explore mode. In the design mode, the learners are given the overhead view of the garden, where they can place objects like trees. In the explore mode, learners can explore the garden instead by walking through it in a 360-degree 3D environment. Apprentices are invited to switch between the two modes in accordance with their objectives.
- **Constructivism:** In GardenVR, apprentices are given the practical task of designing a garden, and they can experiment with different solutions before completing their garden. For instance, they can plant a tree, observe the consequence and undo the action.
- **Going beyond physical limits:** GardenVR provides the functions of daily, seasonal and yearly changes. Learners can fast forward time to visualize the evolution of the garden, showing the advantage of VR-based simulations to reduce the time demands of experiments.

When tested with gardener apprentices, it was found that GardenVR could support the designing skills of the learners (Kim et al. 2020).

The project 'VR and Mixed-Reality Assessment for Plumbers' is an initiative developed by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in partnership with the Institute of Plumbing South Africa (IOPSA).⁵⁹ Apprentices in the plumbing industry have the opportunity to experience a VR construction site as well as simulations using a digitized, 3D virtual construction site. The VR house offers a virtual environment with activities designed according to the principles of problem-based learning methodologies. In addition to solving interdisciplinary professional and work-related problems, the virtual house forces participants to interact inside a digital interface. Common tasks, such as hot water preparation and rainwater harvesting, then have to be performed digitally and within this virtual environment.

3.3.5 Monitoring, assessing and certifying

A comprehensive and credible mechanism for monitoring and assessing apprentices' performance is an indispensable component of all quality apprenticeship programmes; it is crucial to ensuring apprentices' progress and establishing that they are on the right track to attain the required competences to complete the programme.

Digital technologies provide several opportunities to enhance different forms of assessment, such as formative and summative assessment, competence- and knowledge-based assessment, self assessment and peer assessment.

An e-portfolio is a widely used option for assessments because it can support different kinds of assessment, such as self, peer, competence-based and formative assessment. An e-portfolio is usually defined as a purposeful aggregation of digital objects – such as pictures, videos and any other apprentice artefacts – which presents' to a selected audience evidence of a person's learning and/or ability (Alexiou and Paraskeva 2010). Within this tool, apprentices are invited to select specific evidence for the development of

⁵⁸ For more information, see a video on Immersive 3D virtual environment for vocational education.

⁵⁹ For more information, see the Institute of Plumbing South Africa, <https://www.iopsa.org/>.

their professional knowledge and competences. The process of organizing and selecting evidence for the acquired skill promotes reflection on practices (see section 2.14.2) and on meta-reflection. An e-portfolio can be accessed and monitored by both company tutors and teachers, becoming a shared environment across learning locations (see box 26).

Box 26. E-portfolio-based assessment

The Norwegian government's apprenticeship training offices implemented e-portfolios as a tool to mediate experiences and feedback between apprentices, the training establishment and the training offices. The different e-portfolio systems are versions of the same LMS and target the learning outcomes of the national curricula. Research has shown that branch organizations and trade unions had different expectations toward the e-portfolio system, ranging from technical trades, which emphasize their documentary function, to the prioritization of reflection by the associations of healthcare workers (Nore and Lahn 2014).

Nore and Lahn (2014) proposed stimulating apprentices' explication of work skills through written reflections. Moreover, they suggested combining online and offline sessions with apprentices to make them aware of the function of e-portfolios.

The Future Skills Centre in Canada is investing more than \$1.1 million dollars to research industry adoption models and to pilot an industry engagement model using the VALID-8 tool with 2,000 journeypersons and apprentices. Valid-8, developed by Vametric, is a leading e-portfolio that simplifies the processes of certification, accreditation or competency testing for the candidate as well as the assessor. The VALID-8 tool gives apprentices more control over their own training because it helps them identify their skill gaps and prompts them to develop missing skills.⁶⁰

Game-based assessments and simulations (see box 27) allow assessments design to be more realistic, and also assess skills such as complex problem solving, creativity or collaboration in new ways (Buckley et al. 2021). Game-based or simulation-centred assessments collect a wealth of data that is often missed or unable to be captured by traditional tests. This includes patterns of choices, search behaviours, time-on-task behaviours and, in some cases, eye movement or other biometric information. These rich data sources can be used to help illustrate the cognitive processes that a student engages in as they complete a task (Snow et al. 2015), rather than just focusing on the end product of their performance. Game-based assessments are special because they can mirror the dynamic interaction, structural complexity and feedback loops of real-world situations.

In the long term, integrated assessment systems should rely on game- and simulation-based scenarios to evaluate how students integrate and apply knowledge, skills and abilities. Robust scenarios can involve a subset of content from an academic domain of interest, but perhaps their greatest advantage lies in facilitating the measurement of twenty-first century skills, such as problem solving and collaboration.

Despite the potential of game-based simulations for competence-based assessment, building valid, reliable and fair game-based assessments is considerably more complex and challenging than traditional test development. Success requires an interdisciplinary team with a broad range of skills, including game designers, software engineers and cognitive scientists (Buckley et al. 2021). For this reason, building game-based assessments is relatively expensive and, thus, not always an efficient way to measure simple learning outcomes.

An additional challenge to consider with game-based assessments is the need to make them accessible to students with disabilities. These assessments require careful design, extensive testing and, in some

⁶⁰ For more information, see the Best Practice Models for Industry Engagement page on the Future Skills Centre website.



cases, the invention of new approaches and novel technologies, such as haptic feedback technologies that enable the implementation of touch-based user interfaces, allowing the assessment of visually impaired students (Darrah 2013). Thus, a cost-effective and robust system of assessments might use game-based scenarios in combination with traditional and inexpensive, discrete technology-enhanced assessment items. A good design principle for such an assessment system would be to use relatively inexpensive, traditional assessments where feasible, and reserve the more expensive game-based simulations for measuring more complex competences.

Box 27. Computerized competence-based summative assessment

With the ASCOT+ project, Germany's Federal Ministry for Education and Research supports the development of digital training and assessment for vocational skills in different domains (such as car mechatronics, problem solving for technical systems, commercial problem solving and inter-professional and socio-emotional skills in nursing). In addition to digital training units using videos and simulations, the project is developing assessments that will be used as exams to certify apprentices' skills. For example, an office simulation⁶¹ that fosters the problem-solving competence of trainees in the occupations of industrial clerks and office management clerks is being developed, recording their troubleshooting performances. To this end, authentic problem scenarios are developed for processing within the office simulation. The software deployed makes use of several innovative technologies.

Partly automated procedures for the evaluation of written responses are being put into place to efficiently assess the test results of large groups of participants. The software also analyses the problem-solving competence of learners in real time and uses these log data analyses as a basis for providing individualized support.

3.3.6 Supporting social inclusion and participation

Digital technologies could have a huge impact on participation in apprentice programmes and broader society. However, an unequal distribution of digital infrastructure and equipment, also called the "digital divide", widens social inequalities and marginalizes minorities (Chen and Wellman 2004). Today,

⁶¹ For more information, see the ASCOT+ Projects website, https://www.ascot-vet.net/ascot/en/ascot-projects/ascot-projects_node.html.

millions of people do not have access to the technology and education that have become necessary to participate in the digital economy (ITU 2020). Thus, a priority for any kind of apprenticeship policy should be guaranteeing connectivity and hardware in areas where these are not available. In this sense, partnerships among national governments, non-governmental organizations (NGOs) and ICT companies seem to constitute a viable solution to make both internet and hardware accessible in remote areas (see box 28 and case study 2). However, some authors have pointed out the need to develop an ecosystem that decentralizes technology to avoid risks related to so-called “digital colonialism”, where a few countries create technological dependencies that will lead to perpetual resource extraction from developing countries. Policies should place control directly into the hands of the people in developing countries, rather than rely only on technological products from other countries (Kwet 2019).

Box 28. Using solar panel energy to guarantee connectivity in remote areas

The AMMACHI Lab developed the Mobile Vocational Education (MoVe) van to provide professional training in rural villages in India.⁶² MoVe van units consist of 20 handheld touchscreen devices, a laptop server, one large display monitor, low-cost haptic devices and solar equipment, including solar panels, solar lanterns, batteries, a charge controller, an inverter and a generator for electrical backup. Harnessing the power of solar energy allowed vocational training courses to be run even in high-risk areas during natural disasters and in areas where power is in short supply (Akshay et al. 2012).

Good digital infrastructure is a powerful tool to make education more accessible. It is demonstrative that a country such as Australia, with one third its population living in rural and regional areas, pioneered distance learning to try to equalize educational opportunities approximately one century ago. With the development of distance solutions, the composition of the student population in Australia encompasses rural learners, adult-aged students looking for additional qualifications and on-the-job training, stay-at-home parents looking for a career change or enhancement, part-time students and a large body of international students (Qayyum and Zawacki-Richter 2018). If a lack of digital infrastructure increases social differences, in contrast, the opportunity to access digital devices for learning can be an empowering tool for minority groups (see box 29).

Box 29. Empowering women in India through computer-based programmes

The participation rate of women in the Indian labour market is only 29 per cent, the second-lowest female labour force participation rate in South Asia (Andres et al. 2017). The Women Empowerment Project (WEP) was funded jointly by the United Nations Democracy Fund and Amrita University to reduce this gap. The WEP strived to empower more than 3,000 women through providing a short-term programme consisting of computerized vocational education and training (cTVET), life enrichment education (LEE), community engagement and social support. LEE modules cover transversal topics related to personal, family and community issues; environmental and disaster awareness, preparedness and response; personal empowerment and social participation; civic rights and duties; business and entrepreneurship; and health and hygiene.

The participants were women from a mix of caste groups, religions and ages, but they were all living below or near the poverty line and in mostly rural or peri-urban areas in the states of Kerala and Tamil Nadu. Twenty-eight localities were selected, including at least one community per district in Kerala and four locations in Tamil Nadu. In each of these locations, one local woman was hired and trained to be the facilitator, serving in an indispensable support role to organize the small, group training

classes, encourage consistent participation and support women in overcoming any challenges they faced in the courses (Coley et al. 2021).

The successful implementation of the programme included both economical and personal indicators.

First, the dropout rate of the programme was lower compared to the Indian conventional vocational training model. Moreover, the programme set up 36 microenterprise cooperative groups (involving over 450 WEP participants) and 9 confirmed small businesses. Three months after graduation, more than half (57 per cent) of the participants reported that they had an income and the confidence to use their learned skills professionally. Beyond economic gains, post-training surveys showed a rise in self-confidence among graduates and greater awareness among them of their rights and opportunities.

Digital technologies have been also adopted to empower apprentices with physical, cognitive, psychiatric and health-related impairments (Chelkowski et al. 2019). Different studies showed a low level of participation in the labour market for people with disabilities, despite the recognition of the role of employment in reducing social exclusion (OECD 2012; ILO 2018). Apprenticeships and traineeships have been shown to be beneficial pathways for people with disabilities, particularly for people with intellectual and learning disabilities (Lewis et al. 2011) to obtain qualifications and employment as they combine training and education with practical work. Although the outcomes among apprenticeship and traineeship graduates with disabilities are similar to graduates without disabilities (Ball and John 2005), the former are less likely to undertake and complete apprenticeships and traineeships than their peers without disabilities (National TVET Equity Advisory Council 2011).

In a work by Cocks and Thoresen (2013), the authors found that assistive technology can represent both a main barrier to apprenticeship completion (if they are not provided) and an important opportunity to complete the programme when it is adopted. Similarly, Burgstahler and Bellman (2005) found that the most necessary accommodations for apprentices are: adaptive technology (such as alternate keyboards and mouse interfaces, scanners, screen readers and software to assist with writing); accessible facilities; accessible telecommunication devices; materials in accessible formats; and additional supervision.

An assistive/adaptive technology can be defined as any item or piece of equipment, software or product system that is used to increase, maintain or improve the functional capabilities of persons with physical, cognitive, psychiatric or health-related impairments (Edyburn 2004). Assistive technologies include support for reading, writing, note-taking, hearing and auditory input, vision, dictation/speech-to-text/speech recognition, mind mapping and task management (see box 30).⁶³

Intelligent tutoring systems are a specific kind of adaptive learning technology that enable the personalization of students' learning using different kinds of approaches. They can be used to detect the knowledge (or knowledge gaps) of apprentices; they diagnose the next appropriate steps for apprentices' learning; and they act by providing new exercises, new curriculum units, some form of instruction or simply notifying the teacher (OECD 2021). With well-known applications such as speech-to-text, text-to-speech and auto-captioning, intelligent tutoring systems allow blind, visually impaired, deaf and hard-of-hearing students to participate in traditional educational settings and practices. Further, some smart technologies facilitate the diagnosis and remediation of some special needs (for example, dysgraphia) and support the socio-emotional learning of students with autism so they can more easily participate in apprenticeship programmes.

63 The Augsburg University has published a list of free or low-cost assistive technology that is available to everyone.

Box 30. Assistive technology in European TVET programmes

H-CARE was a 30-month EU-funded project that addressed a specific target audience of unemployed graduate adults, employees in healthcare and sales establishments, and TVET training centres who have enriched their training by offering assistive technologies to salespersons and trade companies (SMEs) in the fields of healthcare and food supplements. The project deliverables were developed based on conducted surveys and need analysis with data collected in Austria, Bulgaria, Romania, and Turkey.

The key project's tangible result was an H-CARE blended TVET training programme consisting of nine training modules, including: 1) training with medical devices and assistive technologies; 2) communication and working with customers with disabilities; and 3) apprenticeship.

► 3.4 Stage 4: Post-training transitions and evaluation

Following the successful completion of a programme (stage 3 of the apprenticeship life cycle), apprentices may enter the labour market or pursue further, higher qualifications. The various pathways undertaken by apprenticeship graduates over the short and long term can serve as an indicator of the quality and effectiveness of an apprenticeship. Therefore, the post-training evaluation of apprenticeship programmes takes into account “tracer” studies that examine apprentices’ transitions after graduation. Evaluation is not an end in itself as it creates a feedback loop for policymakers and practitioners, enabling them to improve the policy environment and programmes. The last stage of the apprenticeship life cycle is divided into two phases (see table 1): 1) transition to the labour market or further education and training; and 2) evaluation of apprenticeship programmes. In the following sections, we will show how digital technologies can be used to enhance the effectiveness and efficiency of these two main processes.

3.4.1 Supporting transition to the labour market or further education and training

The primary goal of apprenticeships is to facilitate a smooth transition for apprentices to the labour market and enable them to access decent employment. Therefore, support for apprenticeship graduates should be provided by various entities, such as employment services, in relation to job searches, CV writing and job interviewing skills. Job placement counsellors need to be aware of the different possibilities provided by digital technologies to support their transition to the labour market.

This includes the use of professional social media (such as LinkedIn) or the use of artificial agents and bots, which can provide individualized counselling based on information provided by the apprentices (see box 31). These kinds of applications have the power to be easily accessible and cheap, allowing the individual to use them more independently. The ability of apps to give easily consultable and reliable labour-market information is one of the strengths of these systems. However, given the amount of data related to it, presenting labour market information is also a matter of choice in career guidance. Presenting certain types of data (for example, geographically situated, gender-related data, rate of occupation or average income) can encourage certain kinds of choices while deterring others (Fusco et al. 2020).

Box 31. An artificial agent providing career counselling

As various labour markets go through transformations driven by technological change, the traditional approach of in-person counselling for apprentices could be too challenging and costly to scale.

Bob emploi⁶⁴ is a platform that provides coaching and counselling through artificial agents. An AI system based on employment data from the French government was developed to offer free, tailored support to millions of individuals who are, or will be, at risk of unemployment or underemployment. Since launching in October 2016, Bob has provided coaching to more than 150,000 jobseekers. Eighty-nine per cent of the users say they find the advice useful or very useful, and forty-three per cent of successful jobseekers consider Bob crucial to the process of finding their job.

SORPRENDO⁶⁵ is a software product developed by a private company as the main output of the Career Guidelines project, funded by the EU's Leonardo da Vinci Programme in 2009. The aim of this software is to improve the quality of guidance services in Italy through the transfer of an English model of career guidance (International Career Assessment Software created by CASCAiD Ltd., which was until 2017, a company of Loughborough University, United Kingdom) and through the adjustment and improvement of pre-existing Italian educational and occupational databases. The software targets secondary school students, premature school-leavers, workers and the unemployed, and is currently used in lower secondary schools as well as in public employment services in Italy.

3.4.2 Assessing the effectiveness of an apprenticeship programme using learning analytics

Following the completion of an apprenticeship, data should be collected to evaluate the quality of the programme. On the one hand, these metrics are important to demonstrate the program's effectiveness to stakeholders. Indeed, educational institutions are increasingly required to measure, demonstrate, and improve performance (Campbell et al. 2007; EU Expert Group 2010). On the other hand, metrics can support the redesigning of the apprenticeship program in an evidence-based approach (Reimann 2016). Almost all the educational learning platforms and tools mentioned in this report automatically collect and store a huge number of learners' digital footprints, including their written texts, time spent on a task, navigation behaviour, and so on. Recently, researchers and practitioners investigated whether this kind of information could be used to assess the effectiveness of a learning programme or to automatically personalize a training offer with respect to the user's behaviour. Consequently, different fields of research emerged: educational data mining, learning analytics and educational institution analytics.

Educational data mining focuses on methods to explore data that come from educational settings and using those methods to better understand learners and the settings in which they learn. Learning analytics is concerned with the measurement, collection, analysis and reporting of data about learners and their context for the purposes of understanding and optimizing learning and the environment in which it occurs (Kop et al. 2017). Educational institution analytics is similar to learning analytic, but its focus is on educational results at national or international levels.

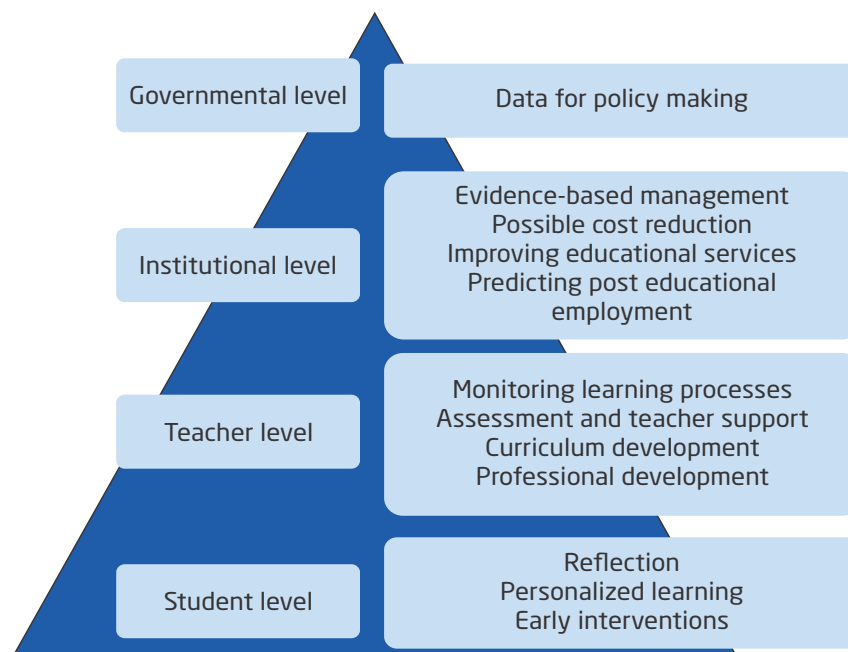
According to these definitions, learning analytics and educational institution analytics have a greater focus on supporting human judgement and decision-making, as well as providing information to empower institutions, instructors and learners (Siemens and Baker 2012). Ferguson (2012) identified three different learning analytics target audiences or interest groups: governments, educational institutions and

64 For more information, see the Bob Emploi website, <https://www.bob-emploi.fr/>.

65 For more information, see the Sorprendo website, <https://www.sorprendo.it/>.

teachers. Although the interests of all three groups overlap, they require analytics working at different scales and at different granularities. In a recent review of the use of learning analytics in TVET contexts, Gedrimiene and colleagues (2020) showed how learning analytics could be used at the student, teacher, administrator and government levels, considering specific TVET characteristics (see figure 5).

Figure 4. Summary of learning analytics possibilities that correspond to TVET education-system levels



Source: Gedrimiene et al. (2020).

Most of the research at the moment focuses on the student and teacher levels. However, in the future, learning analytics could be used further to enable comparisons between institutions with similar apprentices' intakes from different regions, as well as comparisons of educational results using national standards.

At the macro level, organization-wide analytics enable a better understanding of learner cohorts to optimize processes. These include allocating critical resources to do things like reduce dropout rates and increase retention and success rates (see box 32), which can be used to support school admission processes and predict school performance (OECD 2021). Moreover, these analytics could help institutions understand students' future employment prospects better and promote better educational and vocational planning (Avella et al. 2016). Learning analytics could also be used as a part of apprenticeship training, providing individual feedback and cumulative data for human resource purposes, as well as developing cooperation between TVET institutions and workplaces. At the moment, different approaches to learning analytics have been tested in various professional fields, based on the use of different kinds of data (Littlejohn, 2017). For instance, wearable devices were used to track professional networks in healthcare settings (Endedijk 2016). By exploiting these informal professional networks, organizations have a mechanism to improve human social capital and learning. Other approaches used sensors worn on the body (Limbu et al. 2019) and social semantic network analysis (Siadat et al. 2016). As proposed by Liu and colleagues

(2018), it would be interesting in the future to implement an education–industry cooperative system in which schools and companies share data to face the existing information asymmetry in the cooperation.

Ethical implications surrounding the collection, analysis and use of apprentices' data consider the benefits, risks and potential for harm resulting from the collection, analysis and use of apprentices' data (Prinsloo and Slade 2017). Using learning analytics demands a consideration of the ethical dilemmas of balancing open access to data with data privacy protection while also considering the legal issues and ethical risks related to data ownership, data privacy and data availability for the public good. Adopting a learning analytics strategy, thus, requires not only technical skills, but also the ability to reflect upon ethics-, privacy- and security-by-design (UNESCO 2019a).

Learning analytics in the future will essentially be based on and driven by algorithms and machine learning. Therefore, decision makers have to consider how algorithms “reinforce, maintain or even reshape visions of the social world, knowledge and encounters with information” (Williamson 2016, p. 4). Accountability, transparency and regulatory frameworks will be essential elements in the frameworks ensuring ethical learning analytics (Prinsloo and Slade 2016).

Box 32. Using learning analytics to reduce dropout rates and increase retention and success rates

In Finland, all TVET students have a personal competence development plan to support them in acquiring the qualification requirements of their domain. In Helsinki, an AI-based system (AI-HOKS) was developed to help TVET students graduate (and limit their risks of dropping out). Its main goal is to identify the circumstances and phases of learning when students will most likely need support as early as possible, and to provide automated and semi-automated support (for example, mobile coaching). The indicators for early warning and intervention are based on: 1) personal competence development plans (including implementation timelines, acquired competences and self-evaluation); 2) the logging in and use of various tools and learning environments; 3) weekly mobile questionnaires sent to students' mobile phones; and 4) students' feedback provided through the system. With the aim of providing ethical learning analytics, traditional statistical methods that classify or profile students are not used. Instead, ground data are collected as a basis for building machine-learning models that can be used once the system has been in use for a couple of years and larger data sets are available. As of 2021, the system is still being piloted, and information on its effectiveness is not available yet.



▶ 4

Conclusions and recommendations

Conclusions and recommendations

This report presents several evidence-based experiences of technology-enhanced apprenticeship practices collected from various countries, fields and contexts. Each of these practices has been presented referring to the stages and sub-phases of the apprenticeship life cycle as defined by the ILO (2020). As a preliminary remark, it is worth noting that this combination should not be read as definitive nor comprehensive as it was proposed for illustrative purposes. Learning analytics, for example, is presented as a set of methodologies to assess the quality of an apprenticeship programme. However, they can also be used to enhance reflectiveness through formative feedback (Tempelaar et al. 2013). Similarly, we presented 360-degree videos as tools to support apprentices' career choices and awareness on an apprenticeship program. However, 360-degree videos can also be used in the context of training simulation. Decision-makers need to be aware of the affordances provided by each kind of digital technology (Norman 1999; Bower 2008) to critically and flexibly choose when and for what purpose to adopt and integrate them.

A second, immediately consequent remark highlights that an apprenticeship programme does not have to necessarily implement all the digital technologies and practices presented in this report. Apprenticeship providers are invited to assess their priorities and local capabilities and act accordingly. In this conclusion section, we will summarize the key digital transformation issues related to the four stages of the apprenticeship life cycle and some of the key challenges related to them (see the non-exhaustive selection of key challenges and threats in table 4). Commenting on digital transformation issues, we provide recommendations for policy and future research trajectories in six recommendation boxes. Within each recommendation box, a circle indicates its correspondence with the ILO quality apprenticeship building blocks (QABBs) that the proposed policies and research could contribute to supporting (ILO 2017).⁶⁶

Table 4. Key digital transformations and related challenges of the four stages of the apprenticeship life cycle

Stage	Key digital transformation	Key challenges and threats
1) Developing a quality apprenticeship programme	<ul style="list-style-type: none"> The use of big data for job market analysis The development of an international framework for digital credentials and badges enhanced by blockchain 	<ul style="list-style-type: none"> Quality, reliability and feasibility of big data analysis, especially for developing countries Poor level of interoperability of digital credentials and badges
2) Preparing quality training places	<ul style="list-style-type: none"> Dedicated platforms for providing complementary off- or on-the-job training The introduction of the role of digital experts/facilitators in apprenticeship programmes 	<ul style="list-style-type: none"> Resources for negotiating, scaling up and community management Lack of digital skills framework for digital educators in TVET
3) Organizing apprenticeship training	<ul style="list-style-type: none"> The use of mixed-reality technologies (AR, VR, 360-degree videos) and game-based simulations to develop and assess professional competences 	<ul style="list-style-type: none"> Technical issues, costs of development, infrastructural requirements Research on pedagogical designs required
4) Post-training transition and evaluation	<ul style="list-style-type: none"> AI to provide individualized career advice Learning and educational institution analytics for programme assessment 	<ul style="list-style-type: none"> Bias reiterated by AI algorithms Ethical implications around the collection, analysis and use of personal data

Source: Authors' analysis.

⁶⁶ The ILO (2017) identifies six quality building blocks to developing quality apprenticeship systems: 1) Meaningful social dialogue; 2) Equitable funding arrangements; 3) Robust regulatory frameworks; 4) Strong labour market relevance; 5) Clear roles and responsibilities; 6) Inclusiveness.

► 4.1 Key digital transformation issues and the related challenges

In the first stage of developing apprenticeship programmes, we identified two key digital transformation issues: the use of big data for enhancing job market analysis, and the development of a framework for managing digital credentials enhanced by blockchain systems.

Big data analytics can be used to map skills by occupation (Boselli et al. 2018), identify discrepancies or obsolete skills (Mezzanzanica et al. 2018), and conduct predictive analyses of the demand for new occupations and new skills in quasi-real time. According to a recent report from the European Training Foundation (Mezzanzanica and Mercorio 2019), the use of big data for labour market analysis would be especially beneficial for developing and transitioning countries to facilitate matches between market demand and supply, to design apprenticeship paths to fit market expectations better, and to compare internal labour markets against cross-border countries to facilitate mobility. However, for these countries, a lack of access to administrative and statistical data and a poor level of use of online job advertisements could challenge the reliability of the analysis. Recommendation box 1 highlights possible actions to develop valid and reliable systems for job market analysis through big data analytics.

Recommendation box 1. Develop valid and reliable systems for job market analysis through big data analytics

Recommendations for policymakers and decision makers: Policymakers should invest in the development of data analytics models to support policy design and evaluation and to build up systems for collecting real-time information. NGOs could provide the needed technical support for this big data analysis, especially for developing countries (see the cases of Malawi and Myanmar in collaboration with UNESCO, Box 3). Ethical standards and privacy regulation must be respected in gathering, storing, processing, analysing and presenting big data. Website owners must be informed: it is advisable to reach an agreement to avoid major disruptions of their activities.

Future research trajectories: Future research should focus on feasibility studies for developing countries to identify, validate and rank internet sources for labour market analysis (Mezzanzanica and Mercorio 2019), especially on how to collect information on blue collar and non-formal job opportunities, which are often not advertised online.

QABBs

1. Labour market relevance
2. Regulatory framework

Digital badges and credentials have the potential to further promote a competence-based approach during the development of an apprenticeship competence framework. This is particularly relevant when digital badges are developed to be aligned with national frameworks (Konert et al. 2017). However, currently, badge interoperability among different institutions still represents a huge limitation. Effort is required at national levels to assess which credentials could be recognized or used within apprenticeship programmes. To best exploit digital badges, credential systems for apprenticeship will need to be based on national qualification systems and developed through coordination among different stakeholders. From a technical perspective, the credential systems can be further supported by blockchain technologies, which could ensure an additional layer of verification of credentials to prevent/reduce fraud (AkaChain 2020), since apprentices' individual data such as education, employment history, badges and credentials are associated with a verified ID.



Although blockchain technology is still in the early stages, it has the potential to provide users with a higher level of control of their personal data (Christ and Helliard 2021), reducing costs related to the management of apprentices' data (Grech and Camilleri 2017) and certified paper-based credentials and diplomas (OECD 2021). Since certificates issued on the blockchain can be automatically verified, educational organizations will no longer need to commit resources to this task, significantly reducing their administrative load and practically eliminating the "after-sales support" they need to provide learners with at the end of their courses (Grech and Camilleri 2017). Recommendation box 2 highlights possible actions to provide national qualification through digital badges and verify it through blockchain.

Recommendation box 2. Provide national qualification through verified and interoperable digital badges

Recommendations for policymakers and decision-makers: Develop 100 per cent secure, interoperable systems, from both the policy and technical perspectives.

Policymakers could develop digital badges for the apprenticeship qualification verified at national levels through blockchain systems. Then, they should ensure that the digital badges are interoperable with international skills or career-related platforms. It is important to bring together a group of experts in certification, blockchain technology and data protection to define the criteria for an open blockchain implementation (Grech and Camilleri 2017).

Future research trajectories: Policymakers and educational institutions would benefit from further research on privacy implications, intellectual property management and digital identities in applying blockchain. Conducting risk assessments on emerging use cases in blockchain would provide an analysis of the current gaps needing to be filled.

QABBs

1. Regulatory framework
2. Labour market relevance

Digital transformation can positively affect the preparation of quality training places, which is the second stage of the apprenticeship life cycle. One of the biggest potential advantages that this report highlights is the possibility to better connect all the actors involved in an apprenticeship programme through

dedicated digital platforms. The report has described a few platforms (for example, mobile applications and websites) that have already been adopted to support collaboration among TVET teachers, company tutors, trainers for intermediary bodies and apprentices in both developed and developing countries (see Recommendation box 3). Although this kind of platform facilitates communication and exchange, TVET school teachers and company tutors need to have the required competences to collaborate with each other to achieve the apprentices' learning as a common goal. Providing the technology does not guarantee trust and exchange among the parts. Training everybody, that is, apprentices as well as educators of all kinds, to be at ease with this kind of platform is a challenge, whose resolution is necessary in order to benefit from the cross-fertilization between the on-the-job and off-the-job components of learning (Caruso et al. 2020).

Enhancing the digital competences of TVET teachers and trainers as well as apprentices is an interrelated, pivotal issue for the preparation of an apprenticeship programme. Digital competence is more than mere technical skills; it includes a set of knowledge, attitudes and skills that allow integrating digital technologies critically and purposefully within a learning path. The report has mentioned a few national and international frameworks of digital competences for educators. However, our review did not identify a specific framework for educators in TVET and apprenticeship programmes. Future policy and research would need to focus on a digital competence framework specific to TVET and apprenticeship educators (Lucas et al. 2021; Cattaneo et al. 2022) by including, for instance, context-specific competences, such as those related to using technology for enhancing connectivity between apprenticeship learning locations, such as school- and work-based tracks (Cattaneo, Gurtner and Felder 2021). Recommendation box 3 highlights possible actions to facilitate the collaboration between and professional development of apprenticeship trainers.

Recommendation box 3. Develop the conditions for collaboration between and professional development of school-based and company-based trainers

Recommendations for policymakers and decision makers: Supporting teachers, company and inter-company tutors' cooperation with apprentices through the adoption of digital technologies specifically designed to nurture connections and a shared professional culture among the actors of the system, independently from their place of activity, whether the school or the workplace. Examples include Realto (described in Box 12) and eDAP (case study 1) as specific online learning environments accessible by different users with appropriate and differentiated rights. Providing the technology is not enough: it is also necessary to build competences and mutual trust to allow collaborations among TVET schools and companies.

To build a thriving community, organizations must ensure they have political and organizational commitment and the financial and human resources not only to start the cooperation, but also support its growth and evolve with the community throughout its life cycle. Digital facilitators can be key figures in this sense. This role has been already introduced in some educational systems and can promote pedagogically sound and effective digital activities both at the organizational and educational levels, within each educational institution and across learning sites (Cattaneo, Bonini et al. 2021).

Future research trajectories: It would be beneficial to develop and access digital competence frameworks specifically designed for TVET and apprenticeship educators by including, for instance, context-specific competences, such as the use of technology for connectivity between apprenticeship learning locations. Currently, most research focuses on TVET teachers' digital competence. In the future, more research should also focus on in-company and inter-company tutors.

QABBs

1. Social dialogue
2. Clear role and responsibilities



This report describes a few innovative technologies that teachers and trainers will be required to increasingly adopt for apprenticeship training (stage three of the apprenticeship life cycle) by integrating school and workplace learning: XR solutions such as AR, VR, 360-degree videos and game-based simulations. Research shows that XR solutions are at least equal in effectiveness as compared to other training methods but provide more positive effects related to motivation, engagement and increased interest, as well as the possibility of providing training situations when danger or cost may make traditional training impossible (Kaplan et al. 2021).

XR technologies have the potential to facilitate learning for apprentices with cognitive and physical disabilities, supporting the development of functional skills such as wayfinding, numeracy, shopping, literacy, emotional and physical competences (Baragash et al. 2020) and job-seeking behaviours (McMahon et al. 2015). When it comes to procedural learning, AR especially was found to save time and costs while reducing error rates (Jetter et al. 2018). Some studies found that AR can be used by company tutors to insert digital “annotations” within the physical workplace, including virtual images, point-of-view videos, voice recordings and 3D models. The advantage of this method is in providing a constant feedback to an apprentice about the workplace, especially when a company tutor cannot be physically present with the apprentice. Another unique advantage of AR compared to other XR technologies is providing the apprentice the opportunity to manipulate physical objects in the workplace and, thus, execute real procedures, such as mechanical assembly or maintenance (Palmarini et al. 2018).

VR, on the other hand, provides apprentices with the opportunity to learn within environments that are not accessible for several reasons: they are too far (for example, for apprentices in rural areas, see case study 2), or are rare or dangerous scenarios (for example, plane crashes). Despite their potential, there are still several limitations related to XR technologies that need to be addressed. Adopting these technologies requires infrastructure (both hardware and software) and the human resources able to design VR and AR applications. Issues related to poor application design (for example, response time, graphical issues and user experience) have negative effects on apprentices’ experiences and consequently on their engagement and learning outcomes. Moreover, if these technologies are used without a careful pedagogical rationale and design, they have no beneficial effect on learning processes.

These challenges can be overcome in different ways. First, projects that allow teachers and trainers to create their own AR/VR experiences without requiring computer programming skills (as shown in the cases of Box 22) can be promoted. In addition, 360-degree videos allow the creation of immersive experiences without any computer programming skills, which is one of the reasons why studies have reported this option as a cost-effective immersive technology for education (Roche et al. 2021). To reduce

or prevent development costs, it is also possible to rely on existing AR/VR applications for training, such as simulators for building an engine in VR or cooking simulators, in addition to partnering with research centres (see case study 2) that can provide competences and resources to implement these technologies in apprenticeship programmes. Recommendation box 4 highlights further possible actions to introduce XR technologies within apprenticeship programmes.

Recommendation box 4. Introducing XR and game-based simulation in apprenticeship

Recommendations for policymakers and decision makers: To implement XR technologies within apprenticeship programmes, policymakers can try to establish partnerships with the private sector or stimulate the production of new learning resources through innovation funds for specific industries. For instance, the US Department of Education established the Small Business Innovation Research programme to give small enterprises access to funding to produce EdTech applications that could later be commercialized. The fund promotes the use of education technology to improve training practices and learning outcomes.⁶⁷ In England, an EdTech Innovation Fund was established by the Nesta Foundation and the Department for Education.⁶⁸ Partnerships among research centres, governments, local companies and NGOs helped introduce innovative digital technologies, including in developing countries, as shown in case study 2, where VR haptic simulators were introduced in rural Indian regions.

QABBs

1. Equitable funding arrangement
2. Labour market relevance
3. Inclusiveness

Future research trajectories: Apprenticeship programmes do not necessarily have to adopt cutting-edge digital solutions, but they must be guided by strong pedagogical approaches (Schwendimann et al. 2015). More research is needed to define pedagogical design principles while introducing XR and game-based simulation in training and learning. Specifically, research should focus on how to integrate traditional learning methods with XR (Kim et al. 2020), and which is the best method to balance the “automation” of training provided by XR with the roles of teacher and trainer (Cuendet et al. 2013). More research is also needed to understand how XR technologies can be adopted by apprentices with cognitive and physical disabilities to improve their performance and consequently reduce barriers related to employment (McMahon et al. 2015). More research on XR applications, which are already available in the market, is needed to test the effectiveness of these solutions for professional learning and skills development. Moreover, applied research should be combined with basic research by investigating the relationship among factors such as the immersion provided by the experience and mental states of the learner (for example, the feeling of being somewhere else, or the feeling of being absorbed while performing a task) and the learning processes.

Eventually, digital technologies can be adopted to ensure the transition from an apprenticeship programme to future employment/educational opportunities and to assess the effectiveness of the apprenticeship programme (stage four of the apprenticeship life cycle). Bots trained through machine learning algorithms are currently in use in a few countries (such as France) to provide individualized counselling based on apprentices’ data (D’Silva et al. 2020). Chatbots could potentially provide four levels of career advisory services: 1) offering information and recommendations; 2) providing interventions in career development; 3) augmenting career counsellors’ work; and 4) providing career counselling. AI can be trained using the same data collected from a labour market analysis based on big data (stage 1).

⁶⁷ For more information, see the Small Business Innovation Research (SBIR) Program page.

⁶⁸ For more information, see the EdTech Innovation Fund page on the Nesta website.

Technically, one of the key challenges in chatbot development is programming. The creation of a chatbot involves the use of natural language processing. A chatbot, as a dialogue system, should be able to understand the content of the dialogue and identify the users' social and emotional needs during the conversation. Chatbot systems should also be able to learn how to provide users with appropriate answers, which can be accomplished through effective programming. For these reasons, it is advisable to use chatbots in combination with other forms of counselling provided by experts. Recommendation box 5 highlights the possible actions that can be taken to use chatbots to support post-apprenticeship training transitions.

Recommendation box 5. Integrating chatbot with career guidance

Recommendations for policymakers and decision makers: The functions of any chatbot should be explicitly detailed, and users should decide how to interact with the bot. Putting together automatic assessment tools (for chatbots) and counselling with an expert could increase the effectiveness of career guidance services. An app or website could serve as a virtual basis for several activities, such as assessment tests for interests/personality/skills. This type of programme should not be conceived for the independent use of an apprentice. While the purposes of the programme and theoretical suggestions about the process of making career choices would be freely available, career guidance activities and providing labour market information should be subject to scheduling an online meeting with a career counsellor (Fusco et al. 2020). Since chatbots collect sensible information about users, standards and privacy regulation must be respected in gathering, storing, processing and analysing user data (see also Recommendation box 1).

Future research trajectories: Researching natural language processing is more difficult when dealing with other world languages than English as most of the research in the field is heavily focused on English. Future work should consider advancements in the researched field, which may have been published in languages other than English with an added focus on establishing gold-standard corpora in these languages (AlShuweih et al. 2021).

QABBs

1. Labour market relevance
2. Inclusiveness

Big data analysis methodologies can also be used to collect different kinds of data to assess the effectiveness of an apprenticeship programme, from the more institutional level (educational institution analytics) to the learners and trainers' level (LA). Chatbots and learning analytics will be increasingly based on and driven by algorithms and machine learning. Therefore, decision makers have to consider the risk that algorithms reinforce, maintain or even reshape stereotypes and biases, for example, toward minorities and disadvantaged groups. One of the biggest challenges while creating chatbots is to develop and be compliant with regulatory frameworks that ensure accountability, transparency and an ethical adoption of learning analytics (Prinsloo and Slade 2017). Recommendation box 6 highlights further possible actions to integrate learning in apprenticeship.

Recommendation box 6. Integrating learning analytics

Recommendations for policymakers and decision makers: Adopting learning analytics requires a certain level of data literacy to be achieved by all stakeholders in the system to support informed decision-making. Thus, it is important to create and offer tools that allow teachers and trainers to easily use learning analytics as well as guidelines for successfully supporting teaching and learning methods for apprentices.

Practitioners can take the lead within their schools in enabling local organizational change, which can, in turn, support teachers, school leaders, companies and apprentices in appreciating and advocating for learning analytics in learning. Local action and readiness for cultural change should precede the development of local policy as it sets the stage for acceptance, supports the stages of adoption, and helps guide the later development of standards, principles and procedures by policymakers. These actions also address the challenge of updating principles and policies by engaging the impacted communities in the continual process of adapting and improving the organizational response to change.

Trustworthy and ethical learning analytics practices are supported by policy mechanisms such as standards, accreditation processes, audits and evidence-based recommendations informed by practice. Strong and focused actions that provide data privacy and security in the context of interoperability are needed; for example, ensuring that the use of health, socioeconomic, and behavioural, social-emotional, and academic data actually advances learning goals rather than other goals of education. This strategy has to guarantee that the control and ownership of data are clear, transparent and controllable by the person who is the subject of the data (see also Recommendation box 1).

Future research trajectories: Research has reported on systems that track and analyse online readings behaviours, attention, engagement, progress and achievement. All these metrics taken together can be used, for example, to identify apprentices at risk of dropping out or to support students with cognitive or physical impairments. Researchers should also focus on how to develop trainers and apprentices learning analytics literacies; in particular, graphicacy⁶⁹ and educational data literacy should be promoted (Ifenthaler et al. 2021).

QABBs

1. Social dialogue
2. Regulatory framework

⁶⁹ Graphicacy refers to the way in which spatial information is communicated other than by words or numbers alone.



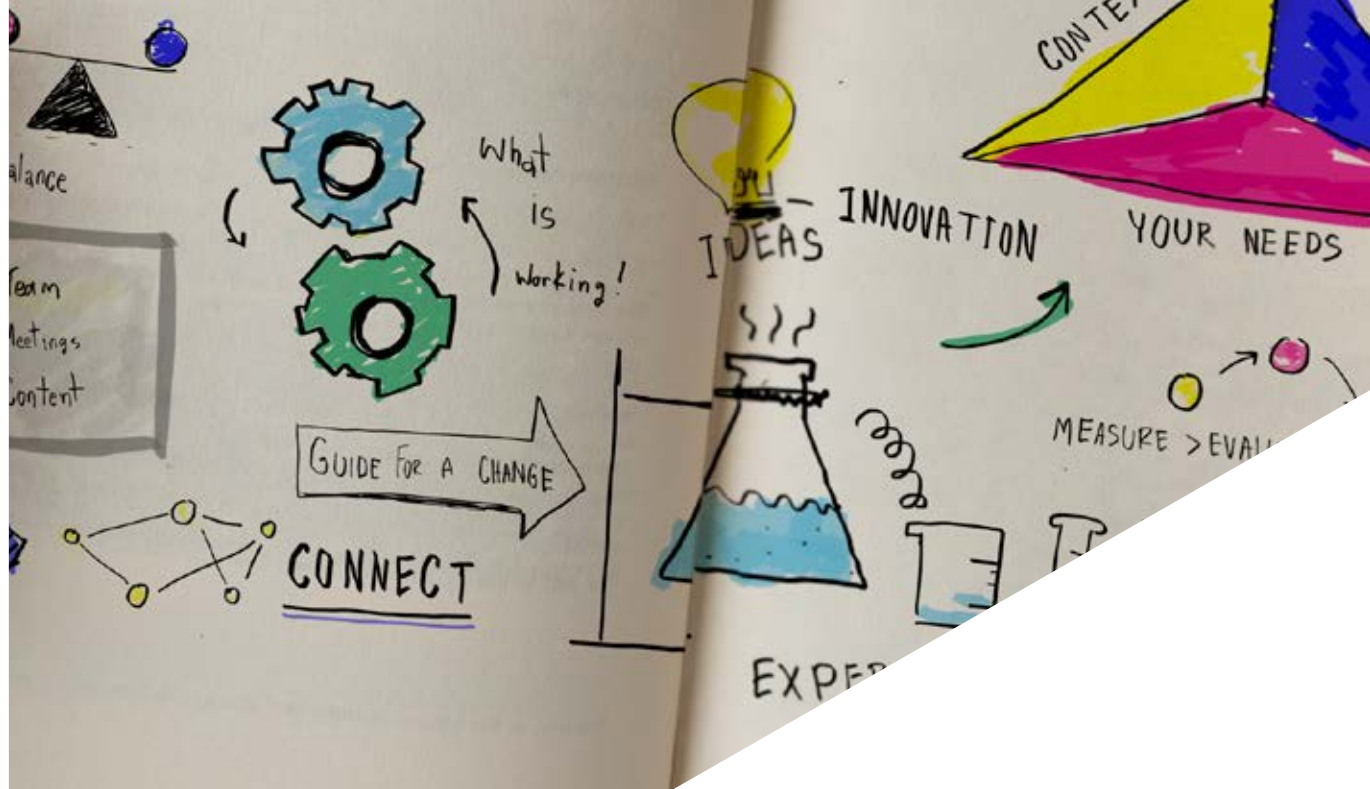
► 4.2 Conclusion

This report shows that digital transformation is a broad phenomenon, with huge implications for economies and consequently for the design and delivery of apprenticeship programmes. In apprenticeship, digital transformation ranges from socioeconomic transformation to the inter- and intra-individual psychological experience of each apprentice and trainer. At a broader level, apprenticeship programmes need to stay at the pace of Industry 4.0. Big data, machine learning, artificial intelligence, robotics and the Internet of Things will continue to shape, to different extents, workplaces and professional practices, providing on the one hand, an opportunity for sustainable growth (Diem 2020) and on the other hand, risks related to privacy issues (Janssen et al. 2013), digital colonialism (Kwet 2019), digital divide (ITU 2020) and skills obsolescence (Frey and Osborne 2017).

Although the digital transformation of apprenticeships had already started before the beginning of the COVID-19 pandemic, social distancing prescriptions imposed further reflection on the opportunities offered by digital technologies for workplace learning, as well as the limitations and constraints to which technology exposes its users. The health emergency made evident all the barriers that prevent a successful and equal digital transformation of workplace learning, such as a lack of infrastructure, digital strategy and the digital competences of both trainers and apprentices in both developing and developed countries. At the same time, it brought the awareness that technologies could not replace existing practices but could support learning under certain conditions. In this report, we argued that facing challenges related to digital transformation can be worthwhile in order to enhance the quality of apprenticeship programmes at different stages.

To achieve its full potential, the digital transformation of apprenticeship will need to be driven not just by technology and research but in full partnership with trainers, apprenticeship providers and the learners themselves. This report has also shown that digital technologies could be used to empower communities through meaningful learning experiences and increasing access to knowledge and professional experiences. However, many of the good practices presented in this report were driven by individual institutions or partnerships. In the future, national and international coordinated actions will be necessary to support an ethical and empowering digital transformation of apprenticeship in developing countries. Putting the right policies in place will therefore be critical to make apprenticeship programmes and workplaces more sustainable and inclusive.

Case Study



▶ 6 Case Study

► Case Study 1

Linking the school and workplace in apprenticeships in Switzerland

One-page summary

Since apprenticeship programs usually combine on-the-job training and work experience with institution-based training (Rosas et al. 2006), cooperation between the school and workplace is a pivotal element to their success. However, apprentices often struggle to connect what they learn at school and in the workplace (Kilbrink and Bjurulf 2013). Moreover, the communication between the school and company tutors is not always adequately supported (Hytonen et al. 2016). This e-DAP case study shows how digital technologies can be exploited to fill the gaps that apprentices experience when they cross the borders between off the-job and on the-job training and at the same time, to support at the same time a better communication between TVET schools and companies.

The e-DAP is a mobile learning solution allowing chef apprentices to create their own e-portfolio and recipe book, which in the Swiss context has also the function of being a learning personal documentation (LPD). The LPD is a mandatory and administrative task for all the VET professions which requires apprentices to document major works and achievements carried out at the company. According to Swiss regulation, the LPD is a task on the apprentice's shoulders, but at the same time, the company trainer has to discuss it with their apprentice at least once per semester. However, often apprentices do not perceive the benefit of keeping a learning documentation (Caruso et al. 2016). Being compliant with the *Erfahrungsraum*, SFUVET designed an electronic version of the LPD.

In the e-DAP, the LPD is conceived as a recipe book, which can be personalized and updated by apprentices based on what they do in the workplace. For each recipe, apprentices can upload a set of pictures of their professional performance taken on a smartphone. Each recipe in the e-DAP is always combined with a few prompts for the apprentices to further reflect on their professional experiences (Mauroux et al. 2016). Company supervisors can comment apprentices' reflections, giving them contextualized and focused feedback. Apprentices can explicitly request such feedback from their supervisors by touching a simple button. In addition, teachers can access the apprentices' pictures and recipes and use them to design specific learning activities for the classroom (Hämäläinen and Cattaneo 2015).

The approach resulted in better learning outcomes for the apprentices in at least three dimensions: knowledge acquisition (Cattaneo et al. 2015), meta-reflection (Mauroux et al. 2013; Motta et al. 2017) and professional performance (Cattaneo and Motta 2020). People using making greater use of the e-DAP also tended to get better final grades, both in the theoretical and practical parts of the exam (Mauroux et al. 2016). Also, Amenduni and Cattaneo (2021) showed that apprentices who used the e-DAP had a higher perception of connectivity (which means that apprentices perceive a good alignment among their school and workplace tutors) compared to a control group who never used it. The scalability of the approach was strongly supported by VET teachers.

After small scale experiments with a restricted group of VET teachers, a couple became "opinion leaders" within their school. They spontaneously arranged opportunities for peer learning and collaboration with their colleagues. Thanks to their contribution, the e-DAP has been currently adopted by a TVET school for five different professions related to food services and by company tutors as well. Countries which require apprentices to maintain a learning documentation within the workplace could find many benefits in digitalizing the learning documentation, such as ease of monitoring, formative assessment, automated feedback, sustaining the communication, better organizing and storing relevant information for both the apprentices and the teachers/trainers (Gianetti 2021).

► Case Study 1

Linking the school and workplace in apprenticeships in Switzerland

Extended

Since apprenticeship programs usually combine on-the-job training and work experience with institution-based training (Rosas et al. 2006), cooperation between the school and workplace is a pivotal element in their success. However, apprentices often struggle to connect what they learn at school and in the workplace (Kilbrink and Bjurulf 2013). Moreover, the communication between the school and company tutors is not always adequately supported (Hytonen et al. 2016). Starting from these concerns, along the years the Swiss Federal University for Vocational Education and Training (SFUVET) investigated the extent to which and under which conditions technologies can be exploited to fill the gaps that apprentices experience when they cross the borders between off the-job and on the-job training. After monitoring several experiences, the Erfahrungsraum pedagogical model was developed and further tested using different technologies (Schwendimann et al. 2015). The model proved to be beneficial not only to apprentices' learning and perceptions of connectivity, but also to encourage a trust-based culture between TVET teachers and company supervisors where each was acknowledged as somebody with a contribution (Cattaneo, Gurtner and Felder 2021).

This was, for example, the case of the e-DAP experience. The e-DAP is a mobile learning solution which allows chef apprentices to create their own e-portfolio and recipe book, which in the Swiss context has also the function of being a learning personal documentation. The LPD is a mandatory and administrative task for all the TVET professions which requires apprentices to document, using specific templates, the major works and achievements carried out at the company. According to Swiss regulation, the LPD is a task on the apprentice's shoulders, but at the same time, the company trainer has to discuss it with their apprentice at least once per semester. However, often apprentices do not perceive the benefit of keeping a learning documentation (Caruso et al. 2016). Being compliant with the Erfahrungsraum, SFUVET designed an electronic version of the LPD and tried to help apprentices realizing this benefit by:

- Better interconnecting apprentices' school- and workplace-based learning experiences without limiting LPD access to the company trainers. Swiss company trainers in many professions think that the TVET teachers could be more involved in the LPD practice (Caruso et al. 2020).
- Enhance the pedagogical potentials of the LPD without confining it to a mere bureaucratic duty.

In the e-DAP, the LPD is conceived as a recipe book which can be personalized and continuously updated by apprentices based on what they do in the workplace. For each recipe, apprentices can upload a set of pictures of their professional performance taken on a smartphone. Each recipe in the e-DAP is always combined with a few prompts for the apprentices to further reflect on their professional experiences (Mauroux et al. 2016). Company supervisors can comment apprentices' reflections, giving them contextualized and focused feedback. Apprentices can explicitly request such feedback from their supervisors by touching a simple button on the e-DAP. In addition, teachers can access the apprentices' pictures and recipes and use them to design specific learning activities in the classroom (Hämäläinen and Cattaneo 2015). In this way, visual information from the workplace becomes material to stimulate theory-driven reflection on their professional practice.

Success factors

The approach resulted in better learning outcomes for the apprentices in at least three important dimensions: knowledge acquisition (Cattaneo et al. 2015), meta-reflection (Mauroux et al. 2013; Motta et al. 2017) and professional performance (Cattaneo and Motta 2020). People using making greater use of the e-DAP also tended to get better final grades, both in the theoretical and practical parts of the exam (Mauroux et al. 2016). Moreover, Caruso et al. (2020) showed that a group of people (apprentices, teachers and company trainers) involved in the chef apprenticeship program with the e-DAP were more aware of the pedagogical potentials of LPD (supporting reflection and connectivity) as compared to a group of chefs who had never used the e-DAP or any other kind of electronic LPD. Also, Amenduni and Cattaneo (2021) showed that apprentices who used the e-DAP had a higher perception of connectivity (which means that apprentices perceived a good alignment among their school and workplace tutors) compared with a control group who had never used it.

Scaling-up and lessons learned

The e-DAP project was sustained by exploiting the network resources at the macro, meso, and micro levels. The first prototype of the e-DAP was funded within the framework of a national research project called Dual-T.⁷⁰ Afterwards, SFUVET entered into an agreement with a local tertiary school in the field of management and computer science to entrust the development of the e-DAP solution to a student as a project towards obtaining their final diploma. Thanks to this second prototype, SFUVET later obtained a sponsorship from the largest Swiss employers' association in the hotel and gastronomy sector to further fund and disseminate the web-based and mobile learning environment.

At the school level, the successful implementation of the project was possible mainly because of the contribution of a few enthusiastic teachers who immediately perceived the added values of the joint pedagogical and technological solution. From the e-DAP experience, SFUVET found out that TVET teachers who disseminated (and duplicated) e-DAP good practices at the school level had the following characteristics: 1) they were former professionals (chefs and cooks) and, therefore, they were able to understand the perspectives and the needs of the companies' tutors; 2) they showed a positive attitude toward the use of technology for teaching; and 3) they were intrinsically motivated to improve their teaching practices.

Although the first characteristic was not present in other similar experiences conducted by SFUVET, the other two – and especially the third – were revealed to be important for the success of the implementation. After small-scale experiments with a restricted group of TVET teachers, a couple of them became “opinion leaders” within their TVET school. They spontaneously arranged opportunities for peer learning and collaboration with their colleagues, following a bottom-up approach. Thanks to their contribution, the e-DAP has been currently adopted by a whole TVET school in five different professions related to food services and by the company tutors as well. TVET teachers reported that the e-DAP platform guaranteed didactic continuity during the first COVID-19 lockdown in Switzerland. Noticeably, the e-DAP project is going on without much supervision by SFUVET, who originally developed the project.

Challenges of implementation

Despite this success, though the requirements for using e-DAP are minimal (this was confirmed by some studies conducted on the usability and ease of use of the application), a group of teachers and trainers reported that the lack of digital skills in their colleagues was often the main barrier in the use of e-DAP in training practices. A further challenge arose from the apprentices' resistance toward writing their reflections in their learning documentation (Gianetti 2021). In replicating this kind of project, it would

70 For more information, see the Dual-T project page on the SFUVET website.

be advisable to think carefully about how to stimulate students' writing and reflective activities, which is essential for professional competence development in every profession (see section 3.3.4.2).

Replicating to other contexts

e-DAP is an established platform in the Italian-speaking region of Switzerland, Ticino. Here, it has naturally become part of the system, being implemented automatically when a new apprentice starts the curriculum. e-DAP's cooperation with the national corporate association made some schools in the French-speaking region adopt it, and other schools in the German-speaking region are considering adopting it. This has allowed e-DAP to start a scaling-up approach, which, however, was not the main objective of the research project in the strict sense. This gives us two general guidelines: scaling up educational technologies requires (a lot of) time to be introduced, accepted and eventually adopted by other people; at the same time, when research has collected empirical evidence on a specific technology's effectiveness for learning, the appropriate (human) resources to still need to be allocated in order to disseminate technological solutions in the field, including training and marketing activities.

Having said that, the e-DAP approach can be replicated to different extents in other professions. For instance, in the Dual-T project, the Realto application (see box 14) was designed to be used by any profession and to be customizable in the learning documentation section to the needs and specificities of the apprentices of the profession using it.

Countries which require apprentices to maintain a learning documentation within the workplace could find many benefits in digitalizing the learning documentation, such as ease of monitoring, formative assessment, automated feedback (also nurtured by the integration of AI-based solutions when feasible), sustaining communication, better organization and storing relevant information for both the apprentices and the teachers/trainers (Gianetti 2021). Developing an application ex-novo could have some advantages (for example, customization and personalization of the environment) although it requires a higher investment in terms of time and costs of development (however, as shown before, it can be relatively accessible). On the other hand, existing technologies can also be exploited and adapted to create a digital learning documentation. For instance, Microsoft applications (such as OneNote) or e-portfolio-related applications (such as Mahara for Moodle), could be used to collect the information of students learning at the workplace and school. However, it is necessary to design learning activities following pedagogies which are thought to support the mutual hybridization between school and workplaces (like the Erfahrungsraum, for example).

To sum up, the e-DAP is an example of a possible way to create a space for communication, reflection and cross-fertilization among apprentices, workplace actors and school tutors by supporting both the organizational and learning components of any apprenticeship programme.

Video 1. Video trailer of the e-DAP available in German (on the left) and in Italian (on the right)



Source: SFUVET (2015).

► Case Study 2

Simulators and virtual reality for VET in rural areas in India

One-page summary

Amrita Multi Modal Applications and Human Computer Interaction Labs (AMMACHI Labs), a research centre affiliated to the Amrita University (Tamil Nadu), uses innovative approaches and technology to overcome traditional obstacles to disadvantaged groups' access to training and employment.

One of the first and amongst the most innovative projects carried out by AMMACHI Labs is the Sakshat Amrita Vocational Education (SAVE) project funded by a grant from the Indian Ministry of Human Resource and Development in 2014. Over the last seven years, project partners have developed 300 VR courses and low-cost, portable, custom-built haptic and touch-based simulators to palliate the lack of the apprentices' hands-on experience or of expensive heavy machinery for various trades including construction, manufacturing, healthcare, garments, home decor, agriculture and automotives. Haptics simulators are devices which provide sensory feedback, such as vibrations, allowing apprentices to gain practical experience in close-to-real working conditions and to develop the required motor skills safely even in the absence of instructors.

In most of the experiences realized by AMMACHI Labs, users received haptic and auditory feedback integrated with desktop VR interfaces that provide users visual representations of professional situations and visual feedback (Jose et al. 2014). For instance, in the virtual workshop for hacksaw training, feedback is displayed on the computer screen, including the cutting speed, the average downward pressure, the number of blades broken in the simulation and an aggregate final score for the exercise based on these variables.

This approach is generalizable for training where accessing real situations is not always possible or opportune: possible harming of patients (for example, in healthcare), destructive or dangerous procedures (for example, working with hacksaws and blades), expensive material or unreachable environments (such as nuclear and deep-water operations) constitute some illustrative cases (Lelevé et al. 2020).

Some of the reported advantages of using haptic simulators is the reduction of waste (such as wood and plastic) and making procedural and fine-motor skills training accessible, even when apprentices cannot attend TVET schools or workplaces. For instance, in this case, apprentices lived in rural areas which were located far away from TVET schools and companies. Transportable haptic simulators and computers were brought to rural areas using a MoVE van (a vehicle which consists of 20 handheld touchscreen devices, a laptop server, one large display monitor, low-cost haptic devices and solar equipment) to bring electrical power and devices to rural areas. The third advantage of the combined use of haptic simulators and VR lies in the reduction of the time that a trainer needs to devote to guiding apprentices. Indeed, the haptic simulators can provide a set of formative feedback through desktop VR. Generally, AMMACHI Labs reported a reduction in the cost for training of about of 50 per cent, thanks to the introduction of haptic simulators.

This case study also shows how a local research centre, like AMMACHI Labs, managed to involve a wide population (47 villages were reached and 5,487 people trained, more than 50 per cent of whom were women), generating economic value (for example, the launch of more than 40 small business) thanks to the support of national investments (United Nations 2021).

► Case Study 2

Simulators and virtual reality for VET in rural areas in India

Extended

More than 90 per cent of the Indian working population is employed in the informal sector, which generates about 60 per cent of the country's economic output (King 2012). The government has launched several schemes to enhance skill development in informal settings (Pilz and Regel 2021), especially focused on rural regions (Andres et al., 2017) that are geographically distant from formal training institutions (Wessels and Pilz 2018).

In response to these challenges, AMMACHI Labs, a research centre affiliated to Amrita University (Tamil Nadu), uses innovative approaches and technology to overcome traditional obstacles to disadvantaged groups' access to training and employment.

One of the first and amongst the most innovative projects carried out by AMMACHI Labs is the Sakshat Amrita Vocational Education (SAVE) project funded by a grant from the Indian Ministry of Human Resource and Development in 2014. Over the last 7 years, project partners have developed low-cost, portable, custom-built haptic and touch-based simulators to palliate the lack of the apprentices' hands-on experience or of expensive heavy machinery for various trades including construction, manufacturing, healthcare, garments, home decor, agriculture and automotives. Haptics simulators are devices which provide sensory feedback, such as vibrations, allowing apprentices to gain practical experience in close-to-real working conditions and to develop the required motor skills safely even in the absence of instructors.

In most of the experiences realized by AMMACHI Labs, users received haptic and auditory feedback integrated with desktop VR interfaces that provide users visual representations of professional situations and visual feedback (Jose et al. 2014). The virtual workshop for hacksaw training is one of the first examples of use of AMMACHI Labs' haptic simulators (Jose et al. 2014). Inside this virtual workshop, the hacksaw, blades, different pipe materials (PVC, copper, brass) are on display with navigation buttons to change blades and materials. The interaction between the trainee and the simulation system is mediated using a haptic simulator (see figure 6) and a mouse (to change variables). The instructions to the trainee are given by both audio output and messages displayed on the screen. The trainee can select the pipe material from the toolbar and use a pencil to draw the cutting position.

After marking the cutting position, the trainee can select the pipe vice to secure the pipe in place. Then, the trainee aligns the hacksaw blade with the line marked on the pipe and moves the hacksaw back and forth. Downward pressure is applied with a backward motion using the haptic simulator to cut a groove in the pipe. Once the groove is formed, the hacksaw is moved back and forth while applying downward force on the forward motion. After the pipe is completely cut, the pipe is shown to separate into two pieces, with the cut piece falling onto the workshop table. The evaluation screen is then displayed, showing the cutting speed, average downward pressure, deviation from the cutting mark, the number of blades broken and an aggregate final score for the exercise based on these variables. Depending on the pipe material selected and on the depth of the required cut, the haptic feedback provided to the trainee varies in magnitude.

The virtual workshop allowed trainers to guarantee safer conditions with a limited number of materials required for practice and training.

Figure 5. Virtual workshop for hacksaw training



Source: Jose et al. (2014).

Video 2. AMMACHI Labs: Haptic simulators for vocational skill development



Source: AMMACHI Labs.

A similar approach was followed for the training of novices in construction rebar bending skills. Construction rebars (steel-concrete bars meant for reinforcement) provide structural reinforcements for concrete work. This necessitates experts to bend and cut rebars to correctly size and bend the long steel rods before they can be installed. To train apprentices in the building sector, AMMACHI Labs developed a novel haptic-based bar bending simulator in collaboration with a private institute in the field of construction skills training.⁷¹ The haptic training device is combined with a virtual environment and provides manual skill training and evaluation of trainees' prior knowledge (see figure 7). The system provides a multimodal

⁷¹ For more information, see the Construction Skills Training Institutes page on the L&T Construction website.

simulation environment with visual, audio and haptic feedback, like in the virtual workshop for hacksaw. Copies of the simulator are currently being used in the simulation centres of private institutes in Chennai and Delhi.⁷² While the haptic simulator for hacksaw training can be easily transported, the bar-bending simulator is used within the context of a TVET school or workplaces due to its size.

Figure 6. Haptic and VR simulators to train novices in the construction rebar bending skills



Source: Bar Bending Simulator for L&T | AMMACHI Labs & CWEGE

Scalability

AMMACHI Labs had developed over 300 VR courses and simulators for various trades by 2014, including for the construction, manufacturing, healthcare, garments, home decor, agriculture and automotive sectors. This demonstrates the generalizability of the approach for training where accessing real situations is not always possible or opportune; the possible harm caused to patients (for example, in healthcare), destructive or dangerous procedures (for example, working with hacksaws and blades), expensive materials or an unreachable environment (such as nuclear and deep-water operations) constitute some illustrative cases (Lelevé et al. 2020).

PwC (2020)⁷³ estimated that VR training is more cost-effective at scale than classroom training or e-learning. Since VR content initially requires up to a 48 per cent greater investment than similar classroom or e-learning courses, it is essential to have enough of a cohort to help make this approach cost-effective. At 375 learners, VR training achieved cost parity with classroom learning. At 3,000 learners, VR training became 52 per cent more cost-effective than classroom training. At 1,950 learners, VR training achieved

⁷² For more information, see the Bar Bending Simulator for L&T page on the AMMACHI Labs website.

⁷³ For more information, see Seeing is Believing: How virtual reality and augmented reality are transforming business and the economy.

cost parity with e-learning. Therefore, the larger the number of people being trained, the higher is the return in terms of employee time saved during training, course facilitation and cost savings.

Replicability in other contexts

One of the main advantages of using haptic simulators is the reduction of the waste (such as wood and plastic), and this is particularly relevant to make apprenticeship programs more environmentally sustainable. Moreover, the use of haptic simulators with VR (desktop or immersive) guarantees the accessibility of procedural and fine motor skills training even when apprentices cannot attend TVET schools or workplaces. For instance, in this case, apprentices lived in rural areas located far from TVET schools and companies. Transportable haptic simulators and computers were brought to rural areas through a MoVE van, “a solar-powered classroom on wheels” (see box 18). In both developed and developing countries, in cases of lockdowns in the future, governments could decide to provide each apprentice a set of low-cost haptic simulators to practice their procedural skills at home. The third advantage of the combined use of haptic simulators and VR lies in the reduction of the time that a trainer needs to devote to guiding apprentices. Indeed, haptic simulators can provide a set of formative feedback through desktop VR. Finally, we must not forget that these solutions, in the cases we have just discussed, ideally reduce the number of accidents apprentices suffer in the real world. Additionally, AMMACHI Labs also reported a reduction in the cost of training of about of 50 per cent thanks to the introduction of haptic simulators.

In the past, VR was too expensive, complicated and challenging to deploy. According to PwC (2020), the cost of an enterprise headset ecosystem is a one-time fee of less than US\$1,000, and these units can be managed like any other enterprise mobile device and can be used repeatedly to deliver training.⁷⁴

Challenges and solutions

AMMACHI Labs had to face various challenges in delivering these innovative forms of training in rural areas in India. Table 5 describes the three main challenges experienced by the AMMACHI Lab and the solutions they found.

Table 5. Challenges and opportunities in adopting haptic simulators and VR in rural areas in India for professional learning

Challenges	Solutions
Funding the development of the haptic simulators and VR environment	AMMACHI Labs looked for national funding (the Ministry of Human Resource and Development in India), an international partnership with the United Nations, collaborations with local and international universities (UNESCO-UNEVOC 2017) and collaborations with private entities (for example, the L&T Construction Skills Training Institute).
Dealing with low literacy users	AMMACHI Labs has a team of instructional designers, multimedia artists and subject matter experts who develop user-friendly learning environments for rural populations. Keeping user experience principles in mind, AMMACHI collaborators create learning solutions that are designed to work across India’s rich cultural and linguistic diversity.
Bringing electrical power and devices in rural areas	To bring quality vocational education to the otherwise inaccessible regions of the diverse geography of India, AMMACHI Labs designed the MoVE van, a vehicle which consists of 20 handheld, touchscreen devices, a laptop server, one large display monitor, low-cost haptic devices and solar equipment.

Source: Authors’ analysis.

⁷⁴ For more information, see Technology for Skill Development Ammachi Labs by Mr Ajay Balakrishnan.

The AMMACHI Labs case study demonstrates not only that adopting cutting-edge technologies in rural areas in developing countries is feasible, but also that this strategy could even reduce the costs of training and materials in the long run. This case study also shows how a local research centre, like AMMACHI Labs managed to involve a wide population (47 villages reached and 5,487 people trained, more than 50 per cent of whom were women), generating economic value (for example, the launch of more than 40 small business) thanks to the support of national investments (United Nations 2021). In other words, policymakers will likely have a good return on investment if they fund research and development projects in collaboration with research centres and universities, aimed at developing cutting-edge technologies for apprenticeship programs.

References

Aberdour, Mark. 2016. "Transforming Workplace Learning Culture with Digital Badges". In *Foundation of Digital Badges and Micro-Credentials: Demonstrating and Recognizing Knowledge and Competencies*, edited by Dirk Ifenthaler, Nicole Bellin-Mularski and Dana-Kristin Mah, 203-219. Cham: Springer International Publishing.

AkaChain.io. 2020. "Blockchain-Based Digital ID in HR: A Proactive Recruitment". 5 March 2020.

Akçayır, Murat, and Gökçe Akçayır. 2017. "Advantages and Challenges Associated with Augmented Reality for Education: A Systematic Review of the Literature". *Educational Research Review* 20: 1-11.

Nagarajan, Akshay, Kongeseri Sreeram, Aneesh Anand, Ranga Venkataraman, and Rao R. Bhavani. 2012. "MoVE: Mobile Vocational Education for Rural India". In *2012 IEEE International Conference on Technology-Enhanced Education (ICTEE)*, 1-5.

Alexiou, Aikaterini, and Fotini Paraskeva. 2010. "Enhancing Self-Regulated Learning Skills Through the Implementation of an e-Portfolio Tool". *Procedia-Social and Behavioral Sciences* 2 (2): 3048-3054.

Alias, Nor Aziah, and Ahmad Marzuki Zainuddin. 2005. "Innovation for Better Teaching and Learning: Adopting the Learning Management System". *Malaysian Online Journal of Instructional Technology* 2 (2): 27-40.

AlShuweih, Mohamed, Said A. Salloum, and Khaled Shaalan. 2021. "Biomedical Corpora and Natural Language Processing on Clinical Text in Languages Other Than English: A Systematic Review". *Recent Advances in Intelligent Systems and Smart Applications*: 491-509.

Amenduni, Francesca, and Alberto Cattaneo. 2021. "Digitally Enhanced Apprentices' Perception of Connectivity Across Learning Locations". *Pathways in Vocational Education and Training and Lifelong Learning. Proceedings of the 4th Crossing Boundaries Conference in Vocational Education and Training*, Muttentz and Bern, online, 8.-9. April 2021.

Andres, Luis Alberto, Basab Dasgupta, George Joseph, Vinoj Abraham, and Maria Correia. 2017. "Precarious Drop: Reassessing Patterns of Female Labor Force Participation in India". *World Bank Policy Research Working Paper* (8024).

Aprea, Carmela, and Alberto Cattaneo. 2019. "Designing Technology-Enhanced Learning Environments in Vocational Education and Training". In *The Wiley Handbook of Vocational Education and Training*, 373-393.

Assilmia, Fathima, Yun Suen Pai, Keiko Okawa, and Kai Kunze. 2017. "IN360: A 360-Degree-Video Platform to Change Students Preconceived Notions on Their Career". In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, 2359-2365.

Atkins, Liz, and Kevin J. Flint. 2015. "Nothing Changes: Perceptions of Vocational Education in England". *International Journal of Training Research* 13 (1): 35-48.

Autor, David H., and Michael J. Handel. 2013. "Putting Tasks to the Test: Human Capital, Job Tasks, and Wages". *Journal of Labor Economics* 31 (S1): S59-S96.

Avella, John T., Mansureh Kebritchi, Sandra G. Nunn, and Therese Kanai. 2016. "Learning Analytics Methods, Benefits, and Challenges in Higher Education: A Systematic Literature Review". *Online Learning* 20 (2): 13-29.

- Bacca Acosta, Jorge Luis, Silvia Baldiris, Ramon Fabregat, Kinshuk, and Sabine Graf. 2015. "Mobile Augmented Reality in Vocational Education and Training". *Procedia Computer Science* 75: 49-58.
- Bacca-Acosta, Jorge Luis, Silvia Margarita Baldiris Navarro, Ramon Fabregat Gesa, and Sabine Graf. 2014. "Augmented Reality Trends in Education: A Systematic Review of Research and Applications". *Journal of Educational Technology and Society* 17 (4): 133-149.
- Ball, Katrina, and David John. 2005. *Apprenticeship and Traineeship Completion Rates*. Adelaide: NCVER.
- Baragash, Reem Sulaiman, Hosam Al-Samarraie, Louise Moody, and Fahed Zaqout. 2020. "Augmented Reality and Functional Skills Acquisition Among Individuals with Special Needs: A Meta-Analysis of Group Design Studies". *Journal of Special Education Technology*.
- Barrett, Michael, Eivor Oborn, and Wanda Orlikowski. 2016. "Creating Value in Online Communities: The Sociomaterial Configuring of Strategy, Platform, and Stakeholder Engagement". *Information Systems Research* 27 (4): 704-723.
- Bellezza, Andrea, Valeria Caggiano, and Francesca Amenduni. 2018. "Robotica ed economia: linee guida introduttive". *Analysis* 1: 8-17.
- Berglund, Ingrid, and Ingrid Henning Loeb. 2013. "Renaissance or a Backward Step? Disparities and Tensions in Two New Swedish Pathways in VET". *International Journal of Training Research* 11 (2): 135-149.
- Berking, Peter, and Shane Gallagher. 2013. "Choosing a Learning Management System". *Advanced Distributed Learning (ADL) Co-Laboratories* 14: 40-62.
- Bharathi, Ajay Karthic B. Gopinath, and Conrad S. Tucker. 2015. "Investigating the Impact of Interactive Immersive Virtual Reality Environments in Enhancing Task Performance in Online Engineering Design Activities". In *ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*.
- Bingimlas, Khalid Abdullah. 2009. "Barriers to the Successful Integration of ICT in Teaching and Learning Environments: A Review of the Literature". *Eurasia Journal of Mathematics, Science and Technology Education* 5 (3): 235-245.
- Black, J. Stewart, and Hal Gregersen. 2013. *It Starts with One: Changing Individuals Changes Organizations*. Pearson Education.
- Black, J. Stewart, and Patrick van Esch. 2020. "AI-Enabled Recruiting: What Is It and How Should a Manager Use It?" *Business Horizons* 63 (2): 215-226.
- Blackall, Leigh, and Bronwyn Hegarty. 2014. *Open Education Practices: A User Guide for Organisations and Individuals*. Wikibooks.
- Blythe, Stephen E. 2005. "Digital Signature Law of the United Nations, European Union, United Kingdom and United States: Promotion of Growth in E-Commerce with Enhanced Security". *Richmond Journal of Law & Technology* 11 (2): 6.
- Bogoviz, Aleksei V., Vladimir S. Osipov, Marina K. Chistyakova, and Maxim Y. Borisov. 2019. "Comparative Analysis of Formation of Industry 4.0 in Developed and Developing Countries". In *Industry 4.0: Industrial Revolution of the 21st Century*, 155-164. Springer.
- Bosch, Gerhard, and Jean Charest. 2008. "Vocational Training and the Labour Market in Liberal and Coordinated Economies." *Industrial Relations Journal* 39 (5): 428-447.
- Boselli, Roberto, Mirko Cesarini, Fabio Mercorio, and Mario Mezzanzanica. 2018. "Classifying Online Job Advertisements Through Machine Learning". *Future Generation Computer Systems* 86: 319-328.

- Bower, Matt. 2008. "Affordance Analysis–Matching Learning Tasks with Learning Technologies". *Educational Media International* 45 (1): 3-15.
- Brauer, Sanna, Jaana Kettunen, and Ville Hallikainen. 2018. "'Learning Online' for Vocational Teachers: Visualisation of a Competence-Based Approach in Digital Open Badge-Driven Learning". *Ammattikasvatuksen aikakauskirja* 20 (2).
- British Council. 2020. *Supporting the Development of Quality Apprenticeships. I-Work Program Final Report*.
- Brito, Pedro Quelhas, and Jasmina Stoyanova. 2018. "Marker Versus Markerless Augmented Reality. Which Has More Impact on Users?" *International Journal of Human–Computer Interaction* 34 (9): 819-833.
- Buchem, Ilona, and Henrike Hamelmann. 2010. "Microlearning: A Strategy for Ongoing Professional Development". *eLearning Papers* 21 (7): 1-15.
- Buckley, Jack, Laura Colosimo, Rebecca Kantar, Marty McCall, and Erica Snow. 2021. "Game-Based Assessment for Education". *OECD Digital Education Outlook 2021: Pushing the Frontiers with Artificial Intelligence, Blockchain and Robots*: 195.
- Burgstahler, Sheryl, and Scott Bellman. 2005. "Perceived Benefits of Work-Based Learning: Differences Between High School and Postsecondary Students with Disabilities". *The Asia-Pacific Journal of Inclusive Education* 2, no. 1: 1-20.
- Burke, Lilah. 2019. "Who's Completing Microcredentials?" *Inside Higher Ed*.
- Burning Glass Technologies. 2015. *The Human Factor: The Hard Time Employees Have Finding Soft Skills*. Boston, MA: Burning Glass Technologies.
- Calitz, Andre P., Paul Poisat, and Margaret Cullen. 2017. "The Future African Workplace: The Use of Collaborative Robots in Manufacturing". *SA Journal of Human Resource Management* 15 (1): 1-11.
- Campbell, John P., Peter B. DeBlois, and Diana G. Oblinger. 2007. "Academic Analytics: A New Tool for a New Era". *EDUCAUSE review* 42 (4): 47-50.
- Canhoto, Ana Isabel, and Fintan Clear. 2020. "Artificial Intelligence and Machine Learning as Business Tools: A Framework for Diagnosing Value Destruction Potential". *Business Horizons* 63 (2): 183-193.
- Carnevale, Anthony P., Tamara Jayasundera, and Dmitri Repnikov. 2014. "Understanding Online Job Ads Data". Georgetown University, Center on Education and the Workforce, Technical Report (April).
- Carruth, Daniel W. 2017. "Virtual Reality for Education and Workforce Training". 2017 15th International Conference on Emerging eLearning Technologies and Applications (ICETA).
- Caruso, Valentina, Alberto Cattaneo, and Jean-Luc Gurtner. 2016. "Learning Documentations in VET Systems: An Analysis of Current Swiss Practices". *Vocations and Learning* 9 (2): 227-256.
- . 2017. "Creating Technology-Enhanced Scenarios to Promote Observation Skills of Fashion-Design Students". *Form@ re-Open Journal per la formazione in rete* 17 (1): 4-17.
- . 2020. "Exploring the Potential of Learning Documentation as a Boundary Object in the Swiss Vocational Education and Training System". *ZBW (Zeitschrift für Berufs- und Wirtschaftspädagogik) – Beihefte, Band 29*: 213-232.
- Castano-Munoz, Jonatan, Karel Kreijns, Marco Kalz, and Yves Punie. 2017. "Does Digital Competence and Occupational Setting Influence MOOC Participation? Evidence From a Cross-Course Survey". *Journal of Computing in Higher Education* 29 (1): 28-46.

Cattaneo, Alberto, Ahn-Thu Nguyen, and Carmela Aprea. 2016. "Teaching and Learning with Hypervideo in Vocational Education and Training". *Journal of Educational Multimedia and Hypermedia* 25 (1): 5-35.

Cattaneo, Alberto, Ahn-Thu Nguyen, Florinda Sauli, and Carmela Aprea. 2015. "Scuolavisione: Teaching and Learning with Hypervideo in the Swiss Vocational System". *Journal of e-Learning and Knowledge Society* 11 (2): 27-47.

Cattaneo, Alberto, and Elena Boldrini. 2017. "You Learn by Your Mistakes. Effective Training Strategies Based on the Analysis of Video-Recorded Worked-Out Examples". *Vocations and Learning* 10 (1): 1-26.

Cattaneo, Alberto, and Elisa Motta. 2021. "'I Reflect, Therefore I Am ... A Good Professional'. On the Relationship Between Reflection-on-Action, Reflection-in-Action and Professional Performance in Vocational Education". *Vocations and Learning* 14 (2): 185-204.

Cattaneo, Alberto, and Florinda Sauli. 2017. Integrating Interactive Video in a Learning Scenario. Guidelines from IV4VET Project. Swiss Federal Institute for Vocational Education and Training (SFIVET) (Lugano).

Cattaneo, Alberto, Chiara Antonietti, and Martina Rauseo. 2022. "How Digitalised are Vocational Teachers? Assessing Digital Competence in Vocational Education and Looking at Its Underlying Factors". *Computers & Education* 176.

Cattaneo, Alberto, Elena Boldrini, and Francesco Lubinu. 2020. "Take a Look at This! Video Annotation as a Means to Foster Evidence-Based and Reflective External and Self-Given Feedback: A Preliminary Study in Operation Room Technician Training". *Nurse Education in Practice* 44.

Cattaneo, Alberto, Elisa Motta, and Jean-Luc Gurtner. 2015. "Evaluating a Mobile and Online System for Apprentices' Learning Documentation in Vocational Education: Usability, Effectiveness and Satisfaction". *International Journal of Mobile and Blended Learning (IJMBL)* 7 (3): 40-58.

Cattaneo, Alberto, Hans van der Meij, and Florinda Sauli. 2018. "An Empirical Test of Three Instructional Scenarios for Hypervideo Use in a Vocational Education Lesson". *Computers in the Schools* 35 (4): 249-267.

Cattaneo, Alberto, Hans van der Meij, Carmela Aprea, Florinda Sauli, and Carmen Zahn. 2019. "A Model for Designing Hypervideo-Based Instructional Scenarios". *Interactive Learning Environments* 27 (4): 508-529.

Cattaneo, Alberto, Jean-Luc Gurtner, and Joris Felder. 2021. "Digital Tools as Boundary Objects to Support Connectivity in Dual Vocational Education: Towards a Definition of Design Principles". In *Developing Connectivity between Education and Work*, edited by Eva Kyndt, Simon Beausaert and Ilya Zitter, 137-157. Routledge.

Cattaneo, Alberto, Luca Bonini, and Martina Rauseo. 2021. "The 'Digital Facilitator': An Extended Profile to Manage the Digital Transformation of Swiss Vocational Schools". In *Digital Transformation of Learning Organizations*, edited by Dirk Ifenthaler, Sandra Hofhues, Marc Egloffstein and Christian Helbig, 169-187. Cham: Springer International Publishing.

Cavus, Nadire, and Teyang Zabadi. 2014. "A Comparison of Open Source Learning Management Systems". *Procedia-Social and Behavioral Sciences* 143: 521-526.

Cavus, Nadire. 2013. "Selecting a Learning Management System (LMS) in Developing Countries: Instructors' Evaluation". *Interactive Learning Environments* 21 (5): 419-437.

CEDEFOP (European Centre for the Development of Vocational Training). 2018. Updated VET statistics available on CEDEFOP website.

———. 2020a. Spotlight on VET: Germany. Thessaloniki: CEDEFOP.

———. 2020b. "How are European Countries Managing Apprenticeships to Respond to the COVID-19 Crisis?".

CEDEFOP, European Commission, ETF, ILO (International Labour Office), OECD (Organisation for Economic Co-operation and Development), and UNESCO (United Nations Educational, Scientific and Cultural Organization). 2021. *Perspectives on Policy and Practice: Tapping into the Potential of Big Data for Skills Policy*. Luxembourg: Publications Office.

Chankseliani, Maia, Susan James Relly, and Andrea Laczik. 2016. "Overcoming Vocational Prejudice: How Can Skills Competitions Improve the Attractiveness of Vocational Education and Training in the UK?" *British Educational Research Journal* 42 (4): 582-599.

Chatterton, Peter, and Geoff Rebbeck. 2015. *Report: Technology for Employability. Study Into the Role of Technology in Developing Student Employability*. JISC (Bristol, UK).

Checa, David, and Andres Bustillo. 2020. "A Review of Immersive Virtual Reality Serious Games to Enhance Learning and Training". *Multimedia Tools and Applications* 79 (9): 5501-5527.

Chelkowski, Lisa, Zheng Yan, and Kristie Asaro-Saddler. 2019. "The Use of Mobile Devices with Students with Disabilities: A Literature Review". *Preventing School Failure: Alternative Education for Children and Youth* 63 (3): 277-295.

Chen, Wenhong, and Barry Wellman. 2004. "The Global Digital Divide – Within and Between Countries". *IT & Society* 1 (7): 39-45.

Chi, Michelene T. H., and Ruth Wylie. 2014. "The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes." *Educational Psychologist* 49 (4): 219-243.

Chien, Chen-Fu, and Li-Fei Chen. 2008. "Data Mining to Improve Personnel Selection and Enhance Human Capital: A Case Study in High-Technology Industry". *Expert Systems with Applications* 34 (1): 280-290.

Ching, Yu-Hui, Dazhi Yang, YoungKyun Baek, and Sally Baldwin. 2016. "Enhancing Graduate Students' Reflection in E-Portfolios Using the TPACK Framework". *Australasian Journal of Educational Technology* 32 (5): 108-122.

Christ, Katherine L., and Christine V. Helliard. 2021. "Blockchain Technology and Modern Slavery: Reducing Deceptive Recruitment in Migrant Worker Populations". *Journal of Business Research* 131: 112-120.

Christensen, Gayle, Andrew Steinmetz, Brandon Alcorn, Amy Bennett, Deirdre Woods, and Ezekiel Emanuel. 2013. *The MOOC phenomenon: Who Takes Massive Open Online Courses and Why?*

Cocks, Errol, and Stian Thoresen. 2013. *Barriers and Facilitators Affecting Course Completions by Apprentices and Trainees With Disabilities*. NCVER.

Colasante, Meg. 2011. "Using Video Annotation to Reflect on and Evaluate Physical Education Pre-Service Teaching Practice". *Australasian Journal of Educational Technology* 27 (1): 66-88.

Coley, Christopher, Srividya Sheshadri, Sriram Devanathan, and Rao R. Bhavani. 2021. "Contextualizing Women's Empowerment Frameworks With an Emphasis on Social Support: A Study in Rural South India". *Community, Work & Family*: 1-20.

Colman, Dan. 2013. "MOOC Interrupted: Top 10 Reasons Our Readers Didn't Finish a Massive Open Online Course". *Open Culture*.

Cronin, Catherine. 2017. "Openness and Praxis: Exploring the Use of Open Educational Practices in Higher Education". *International Review of Research in Open and Distributed Learning: IRRODL* 18 (5): 15-34.

- Cuendet, Sébastien, Quentin Bonnard, Son Do-Lenh, and Pierre Dillenbourg. 2012. "Designing Augmented Reality for the Classroom". *Computers & Education*: 1-13.
- D'Silva, Godson, Megh Jani, Vipul Jadhav, Amit Bhoir, and Prithvi Amin. 2020. "Career Counselling Chatbot Using Cognitive Science and Artificial Intelligence". In *Advanced Computing Technologies and Applications*, 1-9. Springer.
- Darrah, Marjorie Anne. 2013. "Computer Haptics: A New Way of Increasing Access and Understanding of Math and Science for Students Who Are Blind and Visually Impaired". *Journal of Blindness Innovation and Research* 3 (2): 3-47.
- Delcker, Jan, and Dirk Ifenthaler. 2021. "Teachers' Perspective on School Development at German Vocational Schools during the Covid-19 Pandemic". *Technology, Pedagogy and Education* 30 (1): 125-139.
- Delen, Erhan, Jeffrey Liew, and Victor Willson. 2014. "Effects of Interactivity and Instructional Scaffolding on Learning: Self-Regulation in Online Video-Based Environments". *Computers & Education* 78: 312-320.
- Delfino, Manuela, and Donatella Persico. 2007. "Online or Face-to-Face? Experimenting with Different Techniques in Teacher Training". *Journal of Computer Assisted Learning* 23 (5): 351-365.
- Diem, Hoang Xuan. 2020. "Prospects for Agriculture 4.0 in Developing Countries: Case Studies from Vietnam".
- Baragash, Reem Sulaiman, Hosam Al-Samarraie, Louise Moody, and Fahed Zaqout. 2020. "Augmented Reality and Functional Skills Acquisition Among Individuals with Special Needs: A Meta-Analysis of Group Design Studies". *Journal of Special Education Technology*.
- Boselli, Roberto, Mirko Cesarini, Fabio Mercorio, and Mario Mezzanzanica. 2018. "Classifying Online Job Advertisements through Machine Learning". *Future Generation Computer Systems* 86: 319-328.
- Caruso, Valentina, Alberto Cattaneo, and Jean-Luc Gurtner. 2020. "Exploring the Potential of Learning Documentation as a Boundary Object in the Swiss Vocational Education and Training System". *ZBW (Zeitschrift für Berufs- und Wirtschaftspädagogik) – Beihefte, Band 29*: 213-232.
- Cattaneo, Alberto, Jean-Luc Gurtner, and Joris Felder. 2021. "Digital Tools as Boundary Objects to Support Connectivity in Dual Vocational Education: Towards a Definition of Design Principles". In *Developing Connectivity between Education and Work*, edited by Eva Kyndt, Simon Beusaert and Ilya Zitter, 137-157. Routledge.
- Cattaneo, Alberto, Chiara Antonietti, and Martina Rauseo. 2022. "How Digitalised Are Vocational Teachers? Assessing Digital Competence in Vocational Education and Looking at Its Underlying Factors". *Computers & Education* 176.
- Christ, Katherine L., and Christine V. Helliard. 2021. "Blockchain Technology and Modern Slavery: Reducing Deceptive Recruitment in Migrant Worker Populations". *Journal of Business Research* 131: 112-120.
- Dobricki, Martin, Kevin G. Kim, Alessia E. Coppi, Pierre Dillenbourg, and Alberto Cattaneo. 2021. "Perceived Educational Usefulness of a Virtual-Reality Work Situation Depends on the Spatial Human-Environment Relation". *Research in Learning Technology* 29.
- D'Silva, Godson, Megh Jani, Vipul Jadhav, Amit Bhoir, and Prithvi Amin. 2020. "Career Counselling Chatbot Using Cognitive Science and Artificial Intelligence." In *Advanced Computing Technologies and Applications*, 1-9. Springer.
- Edutechnica. 2018. 6th Annual LMS Data Update.

- Edwards-Stewart, Amanda, Tim Hoyt, and Greg Reger. 2016. "Classifying Different Types of Augmented Reality Technology". *Annual Review of Cyber Therapy and Telemedicine* 14: 199-202.
- Edyburn, Dave L. 2004. "Rethinking Assistive Technology". *Special Education Technology Practice* 5 (4): 16-23.
- Egloffstein, Marc. 2018. "Massive Open Online Courses in Digital Workplace Learning". In *Digital Workplace Learning: Bridging Formal and Informal Learning with Digital Technologies*, edited by Dirk Ifenthaler, 149-166. Heidelberg: Springer.
- Ehlers, Max, Robert Schuwer, and Ben Janssen. 2018. "OER in TVET: Open Educational Resources for Skills Development". UNESCO-UNEVOC International Centre for Technical and Vocational Education and Training.
- Ehlers, Ulf-Daniel. 2011. "Extending the Territory: From Open Educational Resources to Open Educational Practices". *Journal of Open, Flexible and Distance Learning* 15 (2): 1-10.
- Eickelmann, Birgit, and Julia Gerick. 2018. "Herausforderungen und Zielsetzungen im Kontext der Digitalisierung von Schule und Unterricht. Teil 1: Vier Bereiche des Lernens mit digitalen Medien". *Schulverwaltung. Nordrhein-Westfalen* 29 (2): 47-50.
- Elia, Valerio, Maria Grazia Gnoni, and Alessandra Lanzilotto. 2016. "Evaluating the Application of Augmented Reality Devices in Manufacturing from a Process Point of View: An AHP-Based Model". *Expert Systems with Applications* 63: 187-197.
- Endedijk, Maaikje D. 2016. Presentation at the Technology-Enhanced Professional Learning (TePL) Special Interest Group, Glasgow Caledonian University.
- Engeström, Yrjö. 2015. *Learning by Expanding*. Cambridge University Press.
- Ertmer, Peggy A., Anne Ottenbreit-Leftwich, and Cindy S. York. 2006. "Exemplary Technology-Using Teachers: Perceptions of Factors Influencing Success." *Journal of Computing in Teacher Education* 23 (2): 55-61.
- EU Expert Group. 2010. *Assessing Europe's University-Based Research*. European Commission.
- Evi-Colombo, Alessia, Alberto Cattaneo, and Mireille Bétrancourt. 2020. "Technical and Pedagogical Affordances of Video Annotation: A Literature Review". *Journal of Educational Multimedia and Hypermedia* 29 (3): 193-226.
- Evi-Colombo, Alessia. 2020. "Knowledge Acquisition in Nurse Education through Hypervideos". In *Video-Supported Collaborative Learning. Teacher's Manual*, edited by Eila Burns and Minna Koskinen, 44-48. Jyväskylä: JAMK University of Applied Sciences.
- Eyhorn, Frank, Adrian Muller, John P. Reganold, Emile Frison, Hans R. Herren, Louise Luttikholt, Alexander Mueller, Jörn Sanders, Nadia El-Hage Scialabba, and Verena Seufert. 2019. "Sustainability in Global Agriculture Driven by Organic Farming". *Nature Sustainability* 2 (4): 253-255.
- Fain, Paul. 2018. *On-Ramps and Off-Ramps: Alternative Credentials and Emerging Pathways Between Education and Work*. Washington, DC: Inside Higher Education.
- Falloon, Garry. 2020. "From Digital Literacy to Digital Competence: The Teacher Digital Competency (TDC) Framework". *Educational Technology Research and Development* 68 (5): 2449-2472.
- Ferguson, Rebecca. 2012. "Learning Analytics: Drivers, Developments and Challenges". *International Journal of Technology Enhanced Learning* 4 (5-6): 304-317.
- Finkelstein, Jonathan, Erin Knight, and Susan Manning. 2013. "The Potential and Value of Using Digital Badges for Adult Learners Final Report". American Institutes for Research 16.

Frey, Carl Benedikt, and Michael A. Osborne. 2017. "The Future of Employment: How Susceptible are Jobs to Computerisation?" *Technological Forecasting and Social Change* 114: 254-280.

Fusco, Luca, Anna Parola, and Luigia Simona Sica. 2020. "Designing Meaningful Career Tools: A Proposal for an Optimal Use of Technology in Career Guidance". *PSYCHOBIT*.

Gaba, Ashok K., and Sanjaya Mishra. 2016. "Skill Development through MOOC for Inclusive and Sustainable Development: A Review of Policies in the Asian Commonwealth Countries" <http://oasis.col.org/handle/11599/2560>

Gardiner, Adrian, Cheryl Aasheim, Paige Rutner, and Susan Williams. 2018. "Skill Requirements in Big Data: A Content Analysis of Job Advertisements". *Journal of Computer Information Systems* 58 (4): 374-384.

Garzón, Juan, Juan Pavón, and Silvia Baldiris. 2019. "Systematic Review and Meta-Analysis of Augmented Reality in Educational Settings". *Virtual Reality* 23 (4): 447-459.

Gedrimiene, Egle, Anni Silvola, Jouni Pursiainen, Jarmo Rusanen, and Hanni Muukkonen. 2020. "Learning Analytics in Education: Literature Review and Case Examples from Vocational Education". *Scandinavian Journal of Educational Research* 64 (7): 1105-1119.

Geetha, R., and Sree Reddy D. Bhanu. 2018. "Recruitment through Artificial Intelligence: A Conceptual Study". *International Journal of Mechanical Engineering and Technology* 9 (7): 63-70.

Ghisla, Gianni, Elena Boldrini, and Luca Bausch. 2014. "Didattica per situazioni. Una guida per gli insegnanti di formazione professionale". IUFFP (Istituto Universitario Federale per la Formazione Professionale).

Gianetti, Christian. 2021. "Cuochi AFC, apprendere con le nuove tecnologie e nuovo ruolo del docente". Lugano: Lavoro di diploma presso Scuola Universitaria Federale per la Formazione Professionale (SUFFP).

Gigauro, Iza, Ekaterine Gulua, and Zurab Mushkudiani. 2020. "Current Advances in Digital Recruitment of Human Resources and its Potential for Companies". *SEU & Science*.

Grajewski, Damian, Filip Górski, Adam Hamrol, and Przemysław Zawadzki. 2015. "Immersive and Haptic Educational Simulations of Assembly Workplace Conditions". *Procedia Computer Science* 75: 359-368.

Grech, Alexander, and Anthony F. Camilleri. 2017. *Blockchain in Education*. Luxembourg: Publications Office of the European Union.

Gütl, Christian, Rocael Hernández Rizzardini, Vanessa Chang, and Miguel Morales. 2014. "Attrition in MOOC: Lessons Learned from Drop-out Students." In *Learning Technology for Education in Cloud. MOOC and Big Data*. LTEC 2014, edited by Lorna Uden, Jane Sinclair, Yu-Hui Tao and Dario Liberona, 37-48. Cham: Springer.

Hämäläinen, Raija, and Alberto Cattaneo. 2015. "New TEL Environments for Vocational Education – Teacher's Instructional Perspective". *Vocations and Learning* 8 (2): 135-157.

Hilton, John. 2016. "Open Educational Resources and College Textbook Choices: A Review of Research on Efficacy and Perceptions". *Educational Technology Research and Development* 64 (4): 573-590.

Hiranrat, Chamikorn, and Atichart Harncharnchai. 2018. "Using Text Mining to Discover Skills Demanded in Software Development Jobs in Thailand". In *Proceedings of the 2nd International Conference on Education and Multimedia Technology*, 112-116.

Hoy, Matthew B. 2017. "An Introduction to the Blockchain and its Implications for Libraries and Medicine". *Medical Reference Services Quarterly* 36 (3): 273-279.

Huang, Ronghuai, Dejian Liu, Ahmed Tlili, Svetlana Knyazeva, Ting-Wen Chang, Xiangling Zhang, Daniel Burgos, Mohamed Jemni, M. Zhang, and R. Zhuang. 2020. "Guidance on Open Educational Practices During School Closures: Utilizing OER Under COVID-19 Pandemic in Line with UNESCO OER Recommendation". Beijing: Smart Learning Institute of Beijing Normal University.

Hulsman, Robert L., and Jane van der Vloodt. 2015. "Self-Evaluation and Peer-Feedback of Medical Students' Communication Skills Using a Web-Based Video Annotation System: Exploring Content and Specificity". *Patient Education and Counseling* 98 (3): 356-363.

Hylén, Jan. 2021. "Open Educational Resources: Opportunities and Challenges" <https://www.oecd.org/education/ceri/37351085.pdf>

Hytönen, Kaisa, Tuire Palonen, Erno Lehtinen, and Kai Hakkarainen. 2016. "Between Two Advisors: Interconnecting Academic and Workplace Settings in an Emerging Field." *Vocations and Learning* 9 (3): 333-359.

IBM. 2015. "Open Badge Program". IBM Authorized Training — Worldwide.

Ifenthaler, Dirk, and Clara Schumacher. 2016. "Udacity". In *The SAGE Encyclopedia of Online Education*, edited by Steven L. Danver, 1149-1151. Thousand Oaks, CA: Sage.

Ifenthaler, Dirk, and Marc Egloffstein. 2020. "Development and Implementation of a Maturity Model of Digital Transformation". *TechTrends* 64 (2): 302-309.

Ifenthaler, Dirk, David Gibson, Doreen Prasse, Atsushi Shimada, and Masanori Yamada. 2021. "Putting Learning Back into Learning Analytics: Actions for Policy Makers, Researchers, and Practitioners". *Educational Technology Research and Development* 69 (4): 2131-2150.

Illeris, Knud. 2011. *The Fundamentals of Workplace Learning: Understanding How People Learn in Working Life*. Routledge.

ILO (International Labour Office) Skills and Employability Branch. 2021. *Skilling, Upskilling and Reskilling of Employees, Apprentices and Interns During the COVID-19 Pandemic: Findings from a Global Survey of Enterprises*.

ILO (International Labour Office). 2015. "Anticipating and Matching Skills and Jobs – Guidance Note."

———. 2017. *ILO Toolkit for Quality Apprenticeships, Volume 1: Guide for Policy Makers*. ILO Geneva.

———. 2020a. *ILO Toolkit for Quality Apprenticeships, Volume 2: Guide for Practitioners*. ILO Geneva.

———. 2020b. *The Feasibility of Using Big Data in Anticipating and Matching Skills Needs*.

ILO (International Labour Office) GED (Gender, Equality and Diversity), and ILO (International Labour Office) Skills and Employability Branch. 2018. *Making Apprenticeships and Workplace Learning Inclusive of Persons with Disabilities*.

ITU (International Telecommunication Union). 2020. "Measuring Digital Development: Facts and Figures 2020".

Jansen, Renée S., Anouschka van Leeuwen, Jeroen Janssen, Rianne Conijn, and Liesbeth Kester. 2020. "Supporting Learners' Self-Regulated Learning in Massive Open Online Courses". *Computers & Education* 146.

Janssen, José, Slavi Stoyanov, Anusca Ferrari, Yves Punie, Kees Pannekeet, and Peter Sloep. 2013. "Experts' Views on Digital Competence: Commonalities and Differences". *Computers & Education* 68: 473-481.

Jetter, Jérôme, Jörgen Eimecke, and Alexandra Rese. 2018. "Augmented Reality Tools for Industrial

Applications: What are Potential Key Performance Indicators and Who Benefits?" *Computers in Human Behavior* 87: 18-33.

Jordan, Katy. 2015. "Massive Open Online Course Completion Rates Revisited: Assessment, Length and Attrition". *International Review of Research in Open and Distributed Learning* 16 (3): 341-358.

Jose, James, R. Unnikrishnan, Delmar Marshall, and Rao R. Bhavani. 2014. "Haptic Simulations for Training Plumbing Skills". In *2014 IEEE International Symposium on Haptic, Audio and Visual Environments and Games (HAVE) Proceedings*, 65-70. IEEE.

Jovanovic, Jelena, and Vladan Devedzic. 2014. "Open Badges: Challenges and Opportunities". In *International Conference on Web-Based Learning*, 56-65. Cham: Springer.

Kaplan, Alexandra D., Jessica Cruit, Mica Endsley, Suzanne M. Beers, Ben D. Sawyer, and P. A. Hancock. 2021. "The Effects of Virtual Reality, Augmented Reality, and Mixed Reality as Training Enhancement Methods: A Meta-Analysis". *Human Factors* 63 (4): 706-726.

Kato, Shizuka, Victoria Galán-Muros, and Thomas Weko. 2020. "The Emergence of Alternative Credentials". OECD Working Paper.

Kilbrink, Nina, and Veronica Bjurulf. 2013. "Transfer of Knowledge in Technical Vocational Education: A Narrative Study in Swedish Upper Secondary School". *International Journal of Technology and Design Education* 23 (3): 519-535.

Kim, Dongho, Yongseok Lee, Walter L. Leite, and Anne Corinne Huggins-Manley. 2020. "Exploring Student and Teacher Usage Patterns Associated with Student Attrition in an Open Educational Resource-Supported Online Learning Platform". *Computers & Education* 156.

Kim, Kevin Gonyop, Catharine Oertel, Martin Dobricki, Jennifer K. Olsen, Alessia E. Coppi, Alberto Cattaneo, and Pierre Dillenbourg. 2020. "Using Immersive Virtual Reality to Support Designing Skills in Vocational Education". *British Journal of Educational Technology* 51 (6): 2199-2213.

Kimmons, Royce, Charles R. Graham, and Richard E. West. 2020. "The PICRAT Model for Technology Integration in Teacher Preparation". *Contemporary Issues in Technology and Teacher Education* 20 (1): 176-198.

King, Kenneth. 2012. "The Geopolitics and Meanings of India's Massive Skills Development Ambitions". *International Journal of Educational Development* 32 (5): 665-673.

Kirschner, Paul A., John Sweller, and Richard E. Clark. 2006. "Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching". *Educational Psychologist* 41 (2): 75-86.

Konert, Johannes, Ilona Buchem, Lucy Lewis, Grainne Hamilton, and Tim Riches. 2017. "Competency Alignment of Open Badges". *loyoc*: 29.

Kop, Rita, Helene Fournier, and Guillaume Durand. 2017. "A Critical Perspective on Learning Analytics and Educational Data Mining". In *The Handbook of Learning Analytics*, edited by Charles Lang, George Siemens, Alyssa Wise and Dragan Gašević, 319-326. Society for Learning Analytics Research (SoLAR).

Kuhlemeier, Hans, and Bas Hemker. 2007. "The Impact of Computer Use at Home on Students' Internet Skills". *Computers & Education* 49 (2): 460-480.

Kuusisaari, Hanna. 2013. "Teachers' Collaborative Learning – Development of Teaching in Group Discussions". *Teachers and Teaching* 19 (1): 50-62.

Kwet, Michael. 2019. "Digital Colonialism: US Empire and the New Imperialism in the Global South". *Race & Class* 60 (4): 3-26.

- Leavy, Susan. 2018. "Gender Bias in Artificial Intelligence: The Need for Diversity and Gender Theory in Machine Learning". Proceedings of the 1st International Workshop on Gender Equality in Software Engineering, Gothenburg, Sweden.
- Lelevé, Arnaud, Troy McDaniel, and Carlos Rossa. 2020. "Haptic Training Simulation". *Frontiers in Virtual Reality* 1 (3).
- Lewis, Greg, Stian H. Thoresen, and Errol Cocks. 2011. "Post-Course Outcomes of Apprenticeships and Traineeships for People with Disability in Western Australia". *Journal of Vocational Rehabilitation* 35 (2): 107-116.
- Limbu, Bibeg Hang, Halszka Jarodzka, Roland Klemke, and Marcus Specht. 2018. "Using Sensors and Augmented Reality to Train Apprentices Using Recorded Expert Performance: A Systematic Literature Review". *Educational Research Review* 25: 1-22.
- Limbu, Bibeg, Alla Vovk, Halszka Jarodzka, Roland Klemke, Fridolin Wild, and Marcus Specht. 2019. "WEKIT.one: A Sensor-Based Augmented Reality System for Experience Capture and Re-Enactment." In *European Conference on Technology Enhanced Learning*, 158-171. Springer.
- Littlejohn, Allison. 2017. "Learning and Work: Professional Learning Analytics". In *Handbook of Learning Analytics*. Society for Learning Analytics Research – First edition, edited by Charles Lang, George Siemens, Alyssa Wise and Dragan Gašević, 269-277.
- Liu, Qin, Qingchen Guan, Xiaowen Yang, Hongming Zhu, Gill Green, and Shaohan Yin. 2018. "Education-Industry Cooperative System Based on Blockchain". In *2018 1st IEEE International Conference on Hot Information-Centric Networking (HotICN)*, 207-211. IEEE.
- Lucas, Margarida, Pedro Bem-Haja, Fazilat Siddiq, António Moreira, and Christine Redecker. 2021. "The Relation Between In-Service Teachers' Digital Competence and Personal and Contextual Factors: What Matters Most?" *Computers & Education* 160: 104052.
- Lynch, Raymond, Patricia Mannix McNamara, and Niall Seery. 2012. "Promoting Deep Learning in a Teacher Education Programme Through Self- and Peer-Assessment and Feedback". *European Journal of Teacher Education* 35 (2): 179-197.
- Marsh, Brian, Nick Mitchell, and Peter Adamczyk. 2010. "Interactive Video Technology: Enhancing Professional Learning in Initial Teacher Education". *Computers & Education* 54 (3): 742-748.
- Mauroux, Laetitia, Jessica Dehler Zufferey, Elisa Rodondi, Alberto Cattaneo, Elisa Motta, and Jean-Luc Gurtner. 2016. "Writing Reflective Learning Journals: Promoting the Use of Learning Strategies and Supporting the Development of Professional Skills". In *Writing for Professional Development*, 107-128. Brill.
- Mauroux, Laetitia, Jessica Dehler-Zufferey, François Jimenez, Rolf Wehren, Alberto Cattaneo, and Jean-Luc Gurtner. 2013. "Autorégulation des apprentissages et dossiers de formation en formation professionnelle". In *L'apprentissage autorégulé: perspectives théoriques et recherches empiriques*, edited by Jean-Louis Berger and Fredi Büchel, 195-227. Nice: Ovadia.
- McGill, Tanya J, and Jane E Klobas. 2009. "A Task-Technology Fit View of Learning Management System Impact". *Computers & Education* 52 (2): 496-508.
- McMahon, Don, David F. Cihak, and Rachel Wright. 2015. "Augmented Reality as a Navigation Tool to Employment Opportunities for Postsecondary Education Students with Intellectual Disabilities and Autism". *Journal of Research on Technology in Education* 47 (3): 157-172.
- Mezzanzanica, Mario, and Fabio Mercorio. 2019. *Big Data for Labour Market Intelligence: An Introductory Guide*. Torino, Italy: European Training Foundation.

Mezzanzanica, Mario, Fabio Mercorio, and Emilio Colombo. 2018. "Digitalisation and Automation: Insights from the Online Labour Market." In *Developing Skills in a Changing World of Work: Concepts, Measurement and Data Applied in Regional and Local Labour Market Monitoring Across Europe*, edited by Christa Larsen, Sigrid Rand, Alfons Schmid and Andrew Dean, 259-282. Augsburg: Rainer Hampp Verlag.

Midoro, Vittorio. 2002. "Dalle comunità di pratica alle comunità di apprendimento virtuali". *Italian Journal of Educational Technology* 10 (1): 3-3.

Midoro, Vittorio. 2013. "Guidelines on adaptation of the UNESCO ICT Competency Framework for Teachers". Moscow: UNESCO Institute for Information Technologies in Education.

Milligan, Colin, and Allison Littlejohn. 2017. "Why Study on a MOOC? The Motives of Students and Professionals". *International Review of Research in Open and Distributed Learning* 18 (2): 92-102.

Moore, Andrew, Neil Butcher, and Sarah Hoosen. 2016. "Using UNESCO's ICT Competency Framework for Teachers in Guyana". M. Ranjan, *ICT Integrated Teacher Education*: 31-45.

Mossel, Annette, Andreas Peer, Johannes Goellner, and Hannes Kaufmann. 2017. "Requirement Analysis on a Virtual Reality Training System for CBRN Crisis Preparedness". In *Proceedings of the 59th Annual Meeting of the ISSS 2015 Berlin, Germany*.

Mossel, Annette, Mario Froeschl, Christian Schoenauer, Andreas Peer, Johannes Goellner, and Hannes Kaufmann. 2017. "VROnSite: Towards Immersive Training of First Responder Squad Leaders in Untethered Virtual Reality". In *2017 IEEE Virtual Reality (VR)*, 357-358. IEEE.

Motta, Elisa, Alberto Cattaneo, and Jean-Luc Gurtner. 2017. "Co-Regulations of Learning in Small Groups of Chef Apprentices: When Do They Appear and What Influences Them?" *Empirical Research in Vocational Education and Training* 9 (1): 15.

Mtebe, Joel S. 2020. "Applying UNESCO ICT Competency Framework to Evaluate Teachers' ICT Competence Levels in Tanzania". In *Handbook of Research on Innovative Pedagogies and Best Practices in Teacher Education*, 350-366. IGI Global.

Mu, Xiangming. 2010. "Towards Effective Video Annotation: An Approach to Automatically Link Notes with Video Content." *Computers & Education*: 1752-1763.

Muir, Tracey. 2014. "Google, Mathletics and Khan Academy: Students' Self-Initiated Use of Online Mathematical Resources." *Mathematics Education Research Journal* 26 (4): 833-852.

Muscolino, Holly, and Marci Maddox. 2020. *Worldwide eSignature software forecast, 2020-2024*.

National VET Equity Advisory Council. 2011. *Equity Blueprint 2011-2016: Creating Futures: Achieving Potential through VET*. NVEAC Melbourne.

Navaridas-Nalda, Fermín, Mónica Clavel-San Emeterio, Rubén Fernández-Ortiz, and Mario Arias-Oliva. 2020. "The Strategic Influence of School Principal Leadership in the Digital Transformation of Schools". *Computers in Human Behavior* 112: 106481.

Nore, Hæge, and Leif Christian Lahn. 2014. "Bridging the Gap Between Work and Education in Vocational Education and Training: A Study of Norwegian Apprenticeship Training Offices and E-Portfolio Systems." *International Journal for Research in Vocational Education and Training* 1 (1): 21-34.

Norman, Donald A. 1999. "Affordance, conventions, and design". *Interactions* 6 (3): 38-43.

North, Max, M., and Sarah North, M. 2016. "A Comparative Study of Sense of Presence of Traditional Virtual Reality and Immersive Environments". *Australasian Journal of Information Systems* 20 (0).

Ocheja, Patrick, Brendan Flanagan, and Hiroaki Ogata. 2018. "Connecting Decentralized Learning Records: A Blockchain-Based Learning Analytics Platform". In *Proceedings of the 8th International Conference on Learning Analytics and Knowledge*, 265-269.

OECD (Organisation for Economic Co-operation and Development). 2020. *Policy Responses to Coronavirus (COVID-19) VET in a Time of Crisis: Building Foundations for Resilient Vocational Education and Training Systems*.

———. 2012. *Sick on the Job? Myths and Realities About Mental Health and Work*. Paris: OECD Publishing.

———. 2015. *Adults, Computers and Problem Solving*.

———. 2016. *Getting Skills Right: Assessing and Anticipating Changing Skill Needs*. OECD.

———. 2019. "Survey of Adult Skills". Programme for the International Assessment of Adult Competencies (PIAAC).

———. 2021. *OECD Digital Education Outlook 2021. Pushing the Frontiers with Artificial Intelligence, Blockchain and Robots*.

Ortoleva, Giulia, and Mireille Bétrancourt. 2016. "Supporting Productive Collaboration in a Computer-Supported Instructional Activity: Peer-Feedback on Critical Incidents in Health Care Education". *Journal of Vocational Education & Training* 68 (2): 178-197.

Ottenbreit-Leftwich, Anne T, Krista D Glazewski, Timothy J Newby, and Peggy A Ertmer. 2010. "Teacher Value Beliefs Associated with Using Technology: Addressing Professional and Student Needs". *Computers & Education* 55 (3): 1321-1335.

Paavola, Sami, Lasse Lipponen, and Kai Hakkarainen. 2004. "Models of Innovative Knowledge Communities and Three Metaphors of Learning". *Review of Educational Research* 74 (4): 557-576.

Palkova, Zuzana, and Ioannis Hatzilygeroudis. 2019. "Virtual Reality and Its Applications in Vocational Education and Training." In *Handbook of Mobile Teaching and Learning*, edited by Zhang Yu (Aimee) and Cristol Dean. Singapore: Springer.

Palmarini, Riccardo, John Ahmet Erkoyuncu, Rajkumar Roy, and Hosein Torabmostaedi. 2018. "A Systematic Review of Augmented Reality Applications in Maintenance". *Robotics and Computer-Integrated Manufacturing* 49: 215-228.

Pérez-Álvarez, Ronald, Jorge Maldonado-Mahauad, and Mar Pérez-Sanagustín. 2018. "Tools to Support Self-Regulated Learning in Online Environments: Literature Review", edited by Viktoria Pammer-Schindler, Mar Pérez-Sanagustín, Hendrik Drachsler, Raymond Elferink and Maren Scheffel, In *Lifelong Technology-Enhanced Learning*, 16-30. Cham: Springer International Publishing.

Perini, Marco, Alberto Cattaneo, and Giuseppe Tacconi. 2019. "Using Hypervideo to Support Undergraduate Students' Reflection on Work Practices: A Qualitative Study." *International Journal of Educational Technology in Higher Education* 16 (1): 29.

Petrovic, Danijela S. 2021. "The Digital Competences of Teachers in South Eastern Europe: A Cross-Country Analysis", Pilot of the Digital Needs Analysis Tool for Teachers (DNATT) 2020. ETF (European Training Foundation).

Pickering, James D, and Bronwen J Swinnerton. 2017. "An Anatomy Massive Open Online Course as a Continuing Professional Development Tool for Healthcare Professionals." *Medical Science Educator* 27 (2): 243-252.

- Pilz, Matthias, and Julia Regel. 2021. "Vocational Education and Training in India: Prospects and Challenges from an Outside Perspective". *Margin: The Journal of Applied Economic Research* 15 (1): 101-121.
- Poce, Antonella, Francesca Amenduni, Mariarosaria Re, and Carlo De Medio. 2020. "Assessing a MOOC User's Experience in a Virtual Mobility Project: Preliminary Results for Quality Enhancement". *Italian Journal of Educational Technology* 28 (1): 62-76.
- Põldoja, Hans. 2009. "EduFeed: Redesigning the Feed Reader for an Open Education". OPEN 2009 – Media Lab Doctor of Arts Symposium, Helsinki, Finland.
- Prifti, Loina, Marlene Knigge, Harald Kienegger, and Helmut Krcmar. 2017. "A Competency Model for 'Industrie 4.0' employees". In *Proceedings der 13. Internationalen Tagung Wirtschaftsinformatik (WI 2017)*, edited by Jan Marco Leimeister and Walter Brenner, 46-60. St. Gallen.
- Palmarini, Riccardo, John Ahmet Erkoyuncu, Rajkumar Roy, and Hosein Torabmostaedi. 2018. "A Systematic Review of Augmented Reality Applications in Maintenance". *Robotics and Computer-Integrated Manufacturing* 49: 215-228.
- Prinsloo, Paul, and Sharon Slade. 2016. "Here Be Dragons: Mapping Student Responsibility in Learning Analytics." In *Developing Effective Educational Experiences Through Learning Analytics*, edited by Mark Anderson and Collette Gavan, 170-188. IGI Global.
- . 2017. "Ethics and Learning Analytics: Charting the (Un)charted." In *Handbook of Learning Analytics*, edited by Charles Lang, George Siemens, Alyssa Wise and Dragan Gašević, 49-57. SoLAR.
- Qayyum, Adnan, and Olaf Zawacki-Richter. 2018. *Open and Distance Education in Australia, Europe and the Americas: National Perspectives in a Digital Age*. Springer Nature.
- Ratnata, I. Wayan. 2013. "Enhancing the Image and Attractiveness of TVET." *Collaboration in TVET* 178.
- Rauseo, Martina, Chiara Antonietti, Francesca Amenduni, Martin Dobricki, and Alberto Cattaneo. 2021. *Les compétences numériques des enseignantes et des enseignants de la formation professionnelle. Rapport sur l'enquête menée à l'été 2020*. IFFP (Institut fédéral des hautes études en formation professionnelle) (Lugano).
- Redecker, Christine, and Yves Punie. 2017. *European Framework for the Digital Competence of Educators: DigCompEdu*. Luxembourg: Publications Office of the European Union.
- Reimann, Peter. 2016. "Connecting Learning Analytics with Learning Research: The Role of Design-Based Research". *Learning: Research and Practice* 2 (2): 130-142.
- Rich, Peter J., and Michael Hannafin. 2010. "Video Annotation Tools: Technologies to Scaffold, Structure, and Transform Teacher Reflection". *Journal of Teacher Education* 60 (1): 52-67.
- Rios, Joseph A., Guangming Ling, Robert Pugh, Dovid Becker, and Adam Bacall. 2020. "Identifying Critical 21st-Century Skills for Workplace Success: A Content Analysis of Job Advertisements". *Educational Researcher* 49 (2): 80-89.
- Roche, Lionel, Kittel Aden, Cunningham Ian, and Cathy Rolland. 2021. "360° Video Integration in Teacher Education: A SWOT Analysis". *Frontiers in Education* 6: 447.
- Rosas, Gianni, Valli Corbanese, ILO (International Labour Office), and International Training Centre of the ILO. 2006. *Glossary of Key Terms on Learning and Training for Work*. Torino, Italy: ILO (International Labour Office).
- Sansone, Nadia, Donatella Cesareni, Ilaria Bortolotti, and Sarah Buglass. 2019. "Teaching Technology-Mediated Collaborative Learning for Trainee Teachers". *Technology, Pedagogy and Education* 28 (3): 381-394.

Sappa, Viviana, and Carmela Aprea. 2014. "Conceptions of Connectivity: How Swiss Teachers, Trainers and Apprentices Perceive Vocational Learning and Teaching Across Different Learning Sites". *Vocations and Learning* 7 (3): 263-287.

Sauli, Florinda, Alberto Cattaneo, and Hans van der Meij. 2018. "Hypervideo for Educational Purposes: A Literature Review on a Multifaceted Technological Tool". *Technology, Pedagogy and Education* 27 (1): 115-134.

Scardamalia, Marlene, and Carl Bereiter. 1994. "Computer Support for Knowledge-Building Communities". *The Journal of the Learning Sciences* 3 (3): 265-283.

Schneider, Bertrand, Patrick Jermann, Guillaume Zufferey, and Pierre Dillenbourg. 2010. "Benefits of a Tangible Interface for Collaborative Learning and Interaction". *IEEE Transactions on Learning Technologies* 4 (3): 222-232.

Schön, Donald A. 2017. *The Reflective Practitioner: How Professionals Think in Action*. Routledge.

Schuer, Robert V., and Ben Janssen. *Open Educational Resources in Technical and Vocational Education and Training*. Fontys Hogescholen (Bonn).

Schwendimann, Beat A., Alberto Cattaneo, Jessica Dehler Zufferey, Jean-Luc Gurtner, Mireille Bétrancourt, and Pierre Dillenbourg. 2015. "The 'Erfahrungsraum': A Pedagogical Model for Designing Educational Technologies in Dual Vocational Systems". *Journal of Vocational Education & Training* 67 (3): 367-396.

Sharples, Mike, and John Domingue. 2016. "The Blockchain and Kudos: A Distributed System for Educational Record, Reputation and Reward". In *European Conference on Technology Enhanced Learning*, 490-496. Springer.

Siadat, Melody, Dragan Gašević, and Marek Hatala. 2016. "Associations Between Technological Scaffolding and Micro-Level Processes of Self-Regulated Learning: A Workplace Study". *Computers in Human Behavior* 55: 1007-1019.

Sicilia, Carmen. 2006. "The Challenges and Benefits to Teachers' Practices in Constructivist Learning Environments Supported by Technology". Master's thesis, McGill University.

Siemens, George, and Ryan S. J. d. Baker. 2012. "Learning Analytics and Educational Data Mining: Towards Communication and Collaboration". In *Proceedings of the 2nd International Conference on Learning Analytics and Knowledge*, 252-254. Vancouver, British Columbia, Canada: Association for Computing Machinery.

Sirakaya, Mustafa, and Ebru Kilic Cakmak. 2018. "Effects of Augmented Reality on Student Achievement and Self-Efficacy in Vocational Education and Training". *International Journal for Research in Vocational Education and Training* 5 (1): 1-18.

Snow, Erica L., Laura K. Allen, Matthew E. Jacovina, and Danielle S. McNamara. 2015. "Does Agency Matter? Exploring the Impact of Controlled Behaviors Within a Game-Based Environment". *Computers & Education* 82: 378-392.

Spangenberg, Pia, and Sarah-Christin Freytag. 2020. "Career Choice of Adolescents: Can Occupational VR 360-Degree Videos Facilitate Job Interest?" In *Proceedings of the 12th International Conference on Computer Supported Education (CSEDU 2020)*, 552-558. Science and Technology Publications.

Spitz-Oener, Alexandra. 2006. "Technical Change, Job Tasks, and Rising Educational Demands: Looking Outside the Wage Structure". *Journal of Labor Economics* 24 (2): 235-270.

Statista. 2021. "Number of Smartphones Sold to End Users Worldwide From 2007 to 2021".

Stenström, Marja-Leena, and Päivi Tynjälä. 2009. "Introduction." In *Towards Integration of Work and Learning: Strategies for Connectivity and Transformation*, edited by Marja-Leena Stenström and Päivi Tynjälä, 3-10. Dordrecht: Springer Netherlands.

Stracke, Christian M. 2017. "The Quality of MOOCs: How to Improve the Design of Open Education and Online Courses for Learners?" In *Learning and Collaboration Technologies. Novel Learning Ecosystems. LCT 2017. Lecture Notes in Computer Science*, edited by Panayiotis Zaphiris and Andri Ioannou, 285-293. Cham: Springer.

SURFnet. 2016. "Whitepaper on Open Badges and Micro-Credentials". Utrecht: SURFnet.

Tappeiner, Lisa, Jacqueline M DiSanto, and Kate Lyons. 2019. "Expanding Access to Education through Open Educational Resources (OERs)". In *Developing Educational Technology at an Urban Community College*, 135-146. Springer.

Tempelaar, Dirk T., André Heck, Hans Cuypers, Henk van der Kooij, and Evert van de Vrie. 2013. "Formative Assessment and Learning Analytics". In *Proceedings of the Third International Conference on Learning Analytics and Knowledge*, edited by Dan Suthers, Katrien Verbert, Erik Duval and Xavier Ochoa, 205-209. New York: Association for Computing Machinery.

Tomczyk, Łukasz, Vladimir Costas Jáuregui, Cibelle Albuquerque de La Higuera Amato, Darwin Muñoz, Magali Arteaga, Solomon Sunday Oyelere, Özgür Yaşar Akyar, and Mariana Porta. 2021. "Are Teachers Techno-Optimists or Techno-Pessimists? A Pilot Comparative Among Teachers in Bolivia, Brazil, the Dominican Republic, Ecuador, Finland, Poland, Turkey, and Uruguay". *Education and Information Technologies* 26 (3): 2715-2741.

Tondeur, Jo, Johan van Braak, Guoyuan Sang, Joke Voogt, Petra Fisser, and Anne Ottenbreit-Leftwich. 2012. "Preparing Pre-Service Teachers to Integrate Technology in Education: A Synthesis of Qualitative Evidence". *Computers & Education* 59 (1): 134-144.

Tondeur, Jo, Johan Van Braak, Peggy A Ertmer, and Anne Ottenbreit-Leftwich. 2017. "Understanding the Relationship Between Teachers' Pedagogical Beliefs and Technology Use in Education: A Systematic Review of Qualitative Evidence". *Educational Technology Research and Development* 65 (3): 555-575.

Tripp, Tonya R., and Peter J. Rich. 2012. "The Influence of Video Analysis on the Process of Teacher Change". *Teaching and Teacher Education*: 728-739.

Tsai, Chin-Chung, and Ching Sing Chai. 2012. "The 'Third'-Order Barrier for Technology-Integration Instruction: Implications for Teacher Education". *Australasian Journal of Educational Technology* 28 (6).

Tuomi, Ilkka. 2013. "Open Educational Resources and the Transformation of Education." *European Journal of Education* 48 (1): 58-78.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2019a. "Consensus on Artificial Intelligence and Education: Outcome Document". In *International Conference on Artificial Intelligence and Education – 'Planning Education in the AI Era: Lead the Leap'*. Beijing, People's Republic of China.

———. 2019b. *Recommendation on Open Educational Resources (OER)*.

UNESCO-UNEVOC (International Centre for Technical and Vocational Education and Training). 2017. *Ammachi Labs: Empowering Rural Women Through ICT in TVET*.

United Nations, 2021. "Amrita Vishwa Vidyapeetam: A Success Story in the Usage of Technology-Based Vocational Training in Achieving the Sustainable Development Goals".

- van Esch, Patrick, J. Stewart Black, and Joseph Ferolie. 2019. "Marketing AI Recruitment: The Next Phase in Job Application and Selection". *Computers in Human Behavior* 90: 215-222.
- Voogt, Joke, Petra Fisser, Natalie Pareja Roblin, Jo Tondeur, and Johan van Braak. 2013. "Technological Pedagogical Content Knowledge: A Review of the Literature". *Journal of Computer Assisted Learning* 29 (2): 109-121.
- Wang, Xiangyu, Soh K Ong, and Andrew YC Nee. 2016. "A Comprehensive Survey of Augmented Reality Assembly Research". *Advances in Manufacturing* 4 (1): 1-22.
- Weber, K. Matthias, Niklas Gudowsky, and Georg Aichholzer. 2019. "Foresight and Rechnology Assessment for the Austrian Parliament: Finding New Ways of Debating the Future of Industry 4.0". *Futures* 109: 240-251.
- Wessels, Antje, and Matthias Pilz. 2018. "Indien." In *Internationales Handbuch der Berufsbildung*, edited by Philipp Grollmann, Dietmar Frommberger, Ute Clement, Thomas Deissinger, Uwe Lauterbach, Matthias Pilz and Georg Spöttl. Bonn: Federal Institute for Vocational Education and Training.
- Williamson, Ben. 2016. "Coding the Biodigital Child: The Biopolitics and Pedagogic Strategies of Educational Data Science". *Pedagogy, Culture & Society* 24 (3): 401-416.
- World Economic Forum. 2020. "The Future of Jobs Report 2020". World Economic Forum Geneva.
- Wulf, Jochen, Ivo Blohm, Jan Marco Leimeister, and Walter Brenner. 2014. "Massive Open Online Courses". *Business & Information Systems Engineering* 6 (2): 111-114.
- Wüller, Hanna, Jonathan Behrens, Marcus Garthaus, Sara Marquard, and Hartmut Remmers. 2019. "A Scoping Review of Augmented Reality in Nursing". *BMC nursing* 18 (1): 1-11.
- Xi, Mingze, Matt Adcock, and John McCulloch. 2018. "Future Agriculture Farm Management Using Augmented Reality". In *2018 IEEE Workshop on Augmented and Virtual Realities for Good (VAR4Good)*, 1-3. IEEE.
- Yazdanian, Ramtin, Robert West, and Pierre Dillenbourg. 2020. "Keeping Up with the Trends: Analyzing the Dynamics of Online Learning and Hiring Platforms in the Software Programming Domain". *International Journal of Artificial Intelligence in Education*.
- Young, Colleen. 2013. "Community Management that Works: How to Build and Sustain a Thriving Online Health Community". *Journal of Medical Internet Research* 15 (6).
- Zanville, Holly, Kelly Porter, and Evelyn Ganzglass. 2017. *Report on Phase I Study: Embedding Industry and Professional Certifications Within Higher Education, Corporation for a Skilled Workforce*. Indianapolis: Lumina Foundation.
- Zhang, Xiangling, Ahmed Tlili, Fabio Nascimbeni, Daniel Burgos, Ronghuai Huang, Ting-Wen Chang, Mohamed Jemni, and Mohamed Koutheair Khribi. 2020. "Accessibility Within Open Educational Resources and Practices for Disabled Learners: A Systematic Literature Review". *Smart Learning Environments* 7 (1): 1-19.
- Zhao, Zhenjie, and Xiaojuan Ma. 2021. "Designing an Artificial Agent for Cognitive Apprenticeship Learning of Elevator Pitch in Virtual Reality". *IEEE Transactions on Cognitive and Developmental Systems*.
- Zhenghao, Chen, Brandon Alcorn, Gayle Christensen, Nicholas Eriksson, Daphne Koller, and Ezekiel J. Emanuel. 2015. "Who is Benefiting from MOOCs, and Why". *Harvard Business Review*.
- Zhong, Zhi-Jin. 2011. "From Access to Usage: The Divide of Self-Reported Digital Skills Among Adolescents". *Computers & Education* 56 (3): 736-746.



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