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Ernst Andreas Hartmann
Editors

New Digital Work

Digital Sovereignty at the Workplace

INSTITUTE FOR INNOVATION AND TECHNOLOGY

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Peter Hahn is an industrial clerk, business graduate and health economist. He was initially the controller of a large medical laboratory and worked for a global industrial group in the USA. In the post-reunification period, he accompanied the transformation processes of the former GDR health care facilities to the changed financing conditions, both conceptually and in terms of action. Value and process-oriented management approaches became lasting tools for Peter's professional tasks, in business development in and for start-ups, in the design and implementation of international cooperation, in the context of development cooperation for innovation, and as a quality management officer. Currently, Peter Hahn is working on the global orientation of European research funding networks and on sustainable, digitally sovereign business models.

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New Digital Work and Digital Sovereignty at the Workplace – An Introduction

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Abstract. In this chapter, a framework will be presented for analyzing and designing work systems for digital sovereignty, based on sources from action regulation, control (in the psychological sense), and sociotechnical systems theories. The individual contributions of this edited volume are then classified on the basis of this framework. After discussing specific effects regarding the technology, people, and organization dimensions of digital sovereignty, some more overarching or cross-cutting aspects shall be presented. The chapter concludes with some background information on the history of this publication, which is part of a tradition of contributions on the future of (digital) work.

Keywords: Digital sovereignty · Sociotechnical systems · Action regulation theory

1 New Work and Digital Sovereignty

In an introduction to a volume called 'New Digital Work – Digital Sovereignty at the Workplace', two concepts should be clarified in advance:

- What is 'new' about New Digital Work, since digital work has been with us for more than half a century (Myers 1998; Petrick 2020)?
- How can the concept 'sovereignty' be connected to the digital world, and especially to the world of work (Couture and Toupin 2019; Hartmann 2021a)?

The history of digital work, and also of scientific and practical endeavors to analyze, understand, and design digital work, reaches back until immediately after the Second World War (Shackel 1997). Features like direct manipulation interfaces and gesture recognition were conceived of and prototypically realized in the 1960s (Newman 1968).

What, then, is new? Three aspects appear to bring about new qualities of working with digital technology:

- Immersion, the experience of direct interaction with a digitally mediated or (in parts) digitally created world, and the corresponding tendency towards 'invisible', 'vanishing' human-computer interfaces (Dede 2009; Fishkin et al. 1999; Mayer et al. 2023, this volume).

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- The use of Artificial Intelligence (AI) at the workplace, with its potentials to substitute as well as enhance human intelligence, and its effects on a growing lack of transparency of the inner structure and workings of the technology itself (High-Level Expert Group on AI [AI HLEG], 2020; Mueller et al. 2019; Pentenrieder et al. 2023, this volume; Staneva and Elliott 2023, this volume; Zhou et al. 2021).
- Digital labor platforms transforming access to labor markets, contract and working conditions, and workers' rights and opportunities to associate and organize themselves (Harmon and Silberman 2018; ILO – International Labour Organization, 2018, 2021; Yan et al. 2023, this volume)

All these aspects will be addressed in the present volume: Immersion in the context of (global) working environments (Kreuzwieser et al. 2023, this volume; Mayer et al. 2023, this volume), AI in working (Kreuzwieser et al. 2023, this volume; Staneva and Elliott 2023, this volume) and work-related learning (Kimmig et al. 2023, this volume; Windelband 2023, this volume) environments, digital labor and work platforms on a larger scale referring to national or regional labor markets (Yan et al. 2023, this volume).

Regarding the second aspect besides New Work, digital sovereignty, the general discussion covers a broad range of aspects and domains. In their review article, covering scientific literature as well as informal media or publications from social movements, Stephane Couture and Sophie Toupin (Couture and Toupin 2019) identify the following contexts for digital sovereignty:

- Cyberspace sovereignty, referring to the notion that cyberspace itself may be regarded as a sovereign virtual territory, not (necessarily) subject to the sovereignty and authority of national states
- Sovereignty of national states, closely related to the concept of technological sovereignty, which is also discussed as a property or desideratum of national states
- Indigenous digital sovereignty, the use of digital resources by indigenous nations lacking national states and national sovereignty
- Sovereignty of social movements, employing digital technologies to empower themselves facing the power and digital sovereignty of states and big companies
- Sovereignty of the individuals, harnessing digital tools competently for their own purposes

This last aspect, digital sovereignty of the individual, refers to all roles and life domains of humans. Digital sovereignty at the workplace should be a specific part of that, taking into account the specific qualities, structures, and dynamics of work systems and work processes.

To provide a conceptual and theoretical basis, it has been suggested to draw on theories and concepts from work psychology and sociotechnical systems (Hartmann 2021a).

From work psychology, we chose the Dresden School of action regulation theory (Hacker 2005) as a suitable framework for our purposes, because it has been widely applied in ergonomic research and practice in the German-speaking world, provides a broad perspective on human action in work settings, and has also been successfully applied to designing digital work for decades (Hacker 1987).

Furthermore, within the context of action regulation theory, a suitable concept can be identified to conceptualize sovereignty with respect to individuals in work settings. A core meaning of sovereignty – across all domains as described above (Couture and Toupin 2019) – deals with *control*, in the sense of individuals – or groups, movements, corporations, states – having control over their environments. In the context of human work this means: Their working conditions, tasks, tools, working methods.

Rainer Oesterreich has provided a theory combining action regulation and control, which has been used to construct methods for the assessment of working conditions (Oesterreich 1981). This theoretical work may also be fruitful for the description, analysis, and design of digital sovereignty at the workplace, as will be shown in the following section.

To describe human action in work settings appropriately, the whole systemic context, in which human action is embedded, needs to be taken into account. For this purpose, the sociotechnical systems approach is especially well-suited (Cherns 1976; Mühlbradt et al. 2022; Mumford 2006; Trist and Bamforth 1951). Sociotechnical systems consist of technology, people, and organization, being interdependent on and interacting with each other. In designing sociotechnical systems, a joint optimization of all three subsystems is required.

In the following, a framework will be presented for analyzing and designing work systems for digital sovereignty, based on sources from action regulation, control (in the psychological sense), and sociotechnical systems theories.

2 Dimensions of Digital Sovereignty at the Workplace

Following concepts from work psychology, a conceptual matrix for analyzing and designing work systems for digital sovereignty was developed, consisting of three columns and three rows (Hartmann 2022a).

The three columns describe three aspects of digital sovereignty at the workplace:

- Transparency and Explainability: Transparency of the work system as a whole and of the technological system in particular is a prerequisite for humans being able to exercise control. Complex algorithmic and AI-based systems, however, are inherently complex and intransparent – even for the designers of these systems. Thus, transparency must be provided with extra effort. For Machine Learning algorithms like neural networks, the internal structures and processes are principally not accessible for human inspection and understanding; especially in these cases, the inner workings of the algorithm can only be approximated – by other algorithms tuned at describing these inner workings to humans. These are aspects within the domain of Explainable AI, or XAI (AI HLEG, 2020; Mueller et al. 2019; Pentenrieder et al. 2023, this volume).
- Confidence of action – or efficiency (Effizienz) in the sense of Oesterreich (Oesterreich 1981) – refers to the fact that humans, when acting in sociotechnical systems, can be confident that the effects of their action are those which they expected when selecting these actions. Referring to technical systems, this concerns issues like reliability and technical resilience (Hartmann 2021a).

- Finally, freedom of action – divergence (Divergenz) as it is called by Oesterreich (Oesterreich 1981) – describes situations offering humans a range of different courses of action from which they may choose with discretion. This is close to the concepts ‘degrees of freedom’ (Freiheitsgrade) and ‘scope of action’ (Handlungsspielraum) as used in action regulation theory (Hacker 2005; Hartmann 2021a).

	Socio-digital Sovereignty		
	Transparency and Explainability	Confidence of Action (Efficiency)	Freedom of Action (Divergence)
People	**Basic digital skills** Which skills are needed for being able to understand basic structures and processes of the technological system?	**Task-related digital skills** Which skills are needed for being able to operate the system with a high level of confidence and efficiency?	**Broad digital skills** Which skills are needed for being able to pursue a range of goals, actions and operations with the system?
Organization	**Transparency regarding tasks and roles** Is it clear who has which tasks, responsibilities, and how different roles relate to each other?	**Combination of tasks, social support** Are individual tasks and interactions of different roles combined in a way that supports confidence of action?	**Range of discretion** Which degrees of freedom and range of discretion do people have?
Technology	**Transparency and explainability of technology** Is the system in its structures and/or functioning transparent to the users, or are (approximated) explanations for these structures and processes available?	**Technical reliability and resilience** Is the system reliable, will it operate also under adverse conditions?	**Freedom of action as supported by the technology** Does the system offer and support different courses of action or different styles of action to the users?

Fig. 1. Dimensions and facets of digital sovereignty at the workplace (Hartmann 2022a)

The three rows correspond to the three sub-systems of sociotechnical systems – technology, people, and organization.

The combination of these three columns and rows yields nine cells of the matrix, facets of digital sovereignty at the workplace. Figure 1 shows leading questions for each of these facets, to illustrate the meaning of these nine facets. To develop this approach further into a tool for assessing digital sovereignty in practical work settings, a set of in total 40 questions has been provided and tested to cover more details of all these aspects and to be applied in the qualitative assessment of work systems. At the moment, this material is developed further towards a methodology suited for the practical analysis and design of work systems in industry. To this end, the questions will be refined, and these qualitative questions will be supplemented by quantitative rating scales.

In the following, the chapters of this volume will be presented referring to this matrix.

3 The Technology Dimension

A very basic and profound aspect of digital sovereignty at work is captured by Liane Bächler and Hauke Behrendt (Bächler and Behrendt 2023, this volume). They have devoted their research to work participation for people with intellectual disabilities and high support needs, and they investigate the potentials of digital technology – specifically: digital assistance systems – for improving the labor market and work participation of this target group.

In their research, they recorded the following statement of one of these people, having experienced a digitally assisted work environment:

“I did that very well. Made it myself.”

It is hard to conceive of a statement describing the experience of digital sovereignty in a more apt and concise way. Digital sovereignty refers here to the opportunity to participate at all in ‘normal’ work settings, in the regular labor market. The special emphasis is here on the confidence of action aspect: the confidence users have in successfully achieving the results they intended. It also fits nicely into a decades-long discussion of the potentials of digital technology to enhance human intelligence and capabilities, a discussion that has gained new impetus with the advent of AI (Petrick 2020; Rheingold 2000; Zhou et al. 2021).

The dark side of this phenomenon, the replacement of human intelligence and human work by AI, is an issue discussed by Mila Staneva and Stuart Elliott (Staneva and Elliott 2023, this volume). They describe five methodological approaches to assess the impact of AI on workplaces: 1) an approach that focuses on occupational tasks and analyses whether these tasks can be automated; 2) an approach that draws on information from patents to assess computer capabilities; 3) indicators that use AI-related job postings as a proxy for AI deployment in firms; 4) measures relying on benchmarks from computer science; 5) and an approach that compares computer capabilities to human skills using standardized tests developed for humans. They present prototypical results from studies using the respective measurement methodologies and discuss their relative strengths and weaknesses.

Among the research discussed in this chapter, there is – of course – the well-known study by Carl Benedikt Frey and Michael Osborne (Frey and Osborne 2013), which was perceived as indicating a huge potential for AI to replace human labor. Later studies, however, find much smaller impacts of AI on the replacement of jobs (Arntz et al. 2016; Nedelkoska and Quintini 2018). Additionally, all these approaches focus on the potential replacement of existing jobs, less so on the generation of new jobs as stimulated by the same technologies.

In the beginning of this introduction chapter, three phenomena were described as bringing about new qualities to New Digital Work: Immersion, AI, and digital labor platforms. Simon Kreuzwieser, Andreas Kimmig, Felix Michels, Rebecca Bulander, Victor Häfner, Jakob Bönsch, and Jivka Ovtcharova cover the first two of them, immersion and AI (Kreuzwieser et al. 2023, this volume), and additionally Robotic Process Automation. Whereas, due to their field of work, Mila Staneva and Stuart Elliott (Staneva and Elliott 2023, this volume) focus on the effects of technology – AI in this case – on the labor market, the number of jobs affected or potentially replaced, Kreuzwieser and co-authors do not look at the labor market, but rather at the world of work within the companies, and describe the possibilities to improve working conditions by harnessing these three technologies. Regarding AI and Robotic Process Automation, they find that these technologies can relieve employees of repetitive and manual tasks, whereas Virtual Reality is perceived as offering employees new opportunities to collaborate in virtual environments. Similar to Liane Bächler and Hauke Behrendt (Bächler and Behrendt 2023, this volume), they emphasize the potential of advanced digital technologies to improve digital sovereignty, with a special focus on the freedom of action aspect, brought about by new, flexible forms of interaction – human-machine and human-human, mediated through technology –, enabling users to move more freely in time, space, and across different modes of visualization and representation. Additionally, the deliverance from repetitive work opens up new spaces for creativity.

The aspects of confidence of action (Bächler and Behrendt 2023, this volume) and freedom of action (Kreuzwieser et al. 2023, this volume) have now been addressed, remains the aspect of transparency and explainability. A specific and crucial aspect of transparency is the quantification and display of uncertainties regarding the results of algorithmic systems, especially neural networks. Besides giving explanations or approximations of the functional logic of these systems, it is important for the user to know how certain this result is, how big the margin of error, to be able to put this result into context and to decide whether or to which extent to rely on this. Xinyang Wu, Philipp Wagner, and Marco F. Huber investigate methods for this quantification of uncertainty (Wu et al. 2023, this volume). Classical artificial neural networks only compute point estimates and do not provide the user with information regarding the confidence of the estimate, the result of the information processing. Bayesian neural networks extend classical deep neural networks with a probability component and allow the user to view the probability distribution over the prediction. Because of the large number of parameters to be learned, this calculation can only be performed approximately. Several methods have been developed to efficiently learn the parameter distributions for Bayesian neural networks. The respective advantages and disadvantages, as well as the different application areas of these approaches, are discussed in this chapter.

4 The People Dimension

The people dimension of the matrix (Fig. 1) deals with skills, knowledge, competences of people in sociotechnical systems. However, these skills are not only a matter of education or pedagogy. Rather, they are highly contingent on the other two sub-systems: Organizational philosophies define the level and scope of skills needed in every specific position, and technology may contribute decisively to either replacing or enhancing human skills, as was discussed in the previous section. All these organizational and technological factors are subject to choice, to deliberate design.

Taking into account these systemic inter-dependencies, Lars Windelband (Windelband 2023, this volume) refers to three fundamental scenarios for the organizational-technological context, before addressing issues of education:

- Tool scenario/assistance scenario: Design of digital systems with tool character for skilled work. The core idea here is not to replace human work with technology, but rather to use technology in an assistive role to support and enhance skilled human work.
- Automation scenario: Here, conversely, the core idea is to use technology as a tool for the replacement of human work, the effects often being the reduction of the freedom of action of skilled workers and a general devaluation of qualification
- Hybrid scenario: Here, elements of both tool and automation scenario are implemented, and new forms of interaction and cooperation in monitoring and control tasks are leading to new requirements for skilled workers.

Depending on these scenarios, very different challenges and approaches for (continuing) vocational and technical education emerge.

Lars Windelband also provides in-depth information regarding prototypical skills needed for the three facets of digital sovereignty in the first row, the people dimension in Fig. 1, with a focus on task-related digital skills supporting confidence of action.

Furthermore, he discusses a range of digital educational technologies in general, and work-integrated digital assistance systems specifically, regarding their potential for enhancing vocational and technical education. In doing so, he takes up the discourse propagated by Liane Bächler and Hauke Behrendt (Bächler and Behrendt 2023, this volume) and generalizes it towards non-disabled people.

Roman Senderek complements this generic description with a case study from the Mexican automotive industry (Senderek 2023, this volume). In a Mexican-German cooperation, Mexican automotive workers are prepared for new tasks and work environments as brought about by Industry 4.0 (Botthof and Hartmann 2015). The curriculum consists of the following modules:

- Knowledge about new technology-supported and classic concepts of work-related learning in Industry 4.0
- Competence development in the field of productivity management and industrial engineering
- Further training in the field of repair and new production of tools for OEMs and suppliers
- Advanced training in Lean Management methods for Industry 4.0

These competences have a more general orientation than those described by Lars Windelband (Windelband 2023, this volume), and thus refer to broader digital skills, reflecting the freedom of action facet of digital sovereignty (Fig. 1).

When considering skill development and education for New Digital Work, the digital working conditions of the educators have also to be taken into account. Modimowabarwa Kanyane opens this perspective, using the example of the South African higher education system (Kanyane 2023, this volume). Like in other countries, both the Covid-19 pandemic and the fourth industrial revolution (Industry 4.0) have required a digital transformation of the education landscape to offer quality education using digital learning environments. Consequently, many universities have adopted technological tools and applications as part of their teaching and learning environments. In South Africa, however, the society at large and also the higher education system specifically are characterized by tremendous inequalities, reflecting the wide gap between privileged white and disadvantaged black environments. As a consequence, students as well as teaching staff, especially at black universities, are struggling to get sufficient access to the resources and tools for digital learning, in some cases and regions extending to the precarious or lacking access to radio, television, electricity, or internet connectivity. The South African government has initiated several measures to support academic staff as well as students in coping with the challenges of transformation, like Staffing South Africa's Universities Framework (SSAUF), the New Generation of Academics Programme (nGAP), the University Capacity Development Programme (UCDP), and the University Capacity Development Grant (UCDG). Regarding the sharp inequalities, however, much remains to be done to give all academic staff a fair opportunity to teach, and all students to learn with digital tools in South Africa.

Andreas Kimmig, Jieyang Peng, and Jivka Ovtcharova (Kimmig et al. 2023, this volume) also address capacity building and education for digital work. Their aim is to provide a research and education environment suited for the development of capacities and skills for Industry 4.0.

Therefore, Karlsruhe Institute of Technology (KIT, Germany) and Tongji University (Shanghai, People's Republic of China) have initiated the collaborative 'Construction, Reference Implementation and Verification Platform of Reconfigurable Intelligent Production Systems' or the 'Factory Automation Platform', which provides a functional, advanced technical environment for research and education in intelligent reconfigurable and self-configuring production systems. Core technologies like the Industrial Internet of Things (IIoT), digital twins, and AI algorithms (in this case used to identify detrimental vibrations of machine, tool, and workpiece – chatter – in the production process) are included to provide a technical system with powerful functions, thus establishing a learning environment for advanced technical skills in the Industry 4.0 context.

5 The Organization Dimension

Smart Production Systems are a core concept within Industry 4.0 settings, incorporating technologies like Cyber-Physical Systems (CPS), the Internet of Things (IoT), AI. At the same time, Smart Production Systems are a new way of organizing industrial production. Jochen Deuse, René Wöstmann, Vanessa Weßkamp, David Wagstyl, and Christoph Rieger address these issues in their chapter (Deuse et al. 2023, this volume), and expand the topic from operation to planning of Smart Production Systems. Both operation and planning require new forms of flexible, interdisciplinary organization and collaboration. Technologies like cobots enable new forms of flexible coexistence between human and machine in production. The increasing complexity of products and production systems brings conventional improvement approaches from the fields of Lean Management and Six Sigma to their limits. Data science methods allow the analysis of large volumes of data to identify multivariate patterns and correlations in production systems and processes. All of this leads to new requirements for competences, roles, and work organization.

A specific aspect relates to backlog tools informing all team members about tasks, responsibilities, and the current degrees of fulfillment, providing an excellent example of the transparency/organization facet of the analysis and design matrix for digital sovereignty at the workplace (Fig. 1).

Organizational processes on higher management levels refer to strategic thinking and decision-making. Scenario-based foresight, employing data science and AI methods, is a promising tool to support this strategic thinking and decision-making. Scenario-based foresight rests on two assumptions: 1) Networked thinking, i.e., the consideration of the interconnectedness of influence factors, and 2) multiple futures, i.e., it is not possible to predict the future and therefore different development paths must be considered. Patrick Ködding, Christian Koldewey, and Roman Dumitrescu describe and discuss 14 use cases of corporate scenario-based foresight (Ködding et al. 2023, this volume). These use cases can be realized using 23 different digital technologies. Currently, digital technologies (still) play a minor role in scenario-based foresight. Digital technologies primarily provide support for tasks in which large volumes of data are processed and analyzed, e.g., in the context of identifying influence factors. Text mining approaches are particularly suitable for analyzing large amounts of data in order to generate suggestions for influence factors. Other use cases aim at reducing the evaluation effort in determining scenarios or refer to the elaboration of the scenarios. Digital technologies can provide the input for this activity, e.g., by means of a classification of useful documents by a dictionary algorithm; the creative elaboration itself is ultimately carried out by humans. Scenario-based foresight enhances specifically the freedom of action facet regarding the organization (Fig. 1), as it opens up new pathways of thought and action.

Immersive technologies allow organizations to arrange collaboration not only across time and space but also across the reality-virtuality continuum. Anjela Mayer, Jean-Rémy Chardonnet, Polina Häfner, and Jivka Ovtcharova investigate global collaboration in the context of digital transformation and discuss the role of Collaborative Virtual Environments (CVEs) within this transformation process (Mayer et al. 2023, this volume). Like in the educational case discussed above (Kanyane 2023, this volume), Covid-19 as well as Industry 4.0 increased the pressure, and also the opportunity, for organizations to shift towards remote interaction and collaboration.

Challenges for CVEs include the acceptance of these technologies by employees, which in turn is influenced by the convenience and ease of visual perception in VR, avoiding e. g. misperception of distances and scales, the (absence of) cybersickness, and the quality of interaction modalities (e.g. interacting by natural movement, like walking).

CVE application domains include business, engineering, and education, which provides a suitable cross-reference to the topics discussed in the previous section. There are many possible effects of CVE on working conditions, positive ones like meetings being more consistently structured, and negative ones like feelings of being socially disconnected. Regarding the matrix in Fig. 1, the most prominent aspect is the freedom of action/organization facet, because many qualitatively new possibilities for designing collaboration become available.

6 Overarching and Cross-Cutting Aspects

After discussing specific effects regarding the technology, people, and organization dimensions of digital sovereignty, some more overarching or cross-cutting aspects shall be presented. Annelie Pentenrieder, Peter Hahn, Scarlet Schaffrath, Benedikt Krieger, Stefanie Brzoska, Robert Peters, Matthias Künzel, and Ernst Hartmann present an approach that uses the whole matrix as depicted in Fig. 1 as a tool for analyzing and designing the implementation of algorithmic and AI-based technology in sociotechnical systems (Pentenrieder et al. 2023, this volume). As described above, leading questions were formulated for each of the nine facets of digital sovereignty at the workplace.

In co-creation workshops, potential users are presented with design solutions for industrial work systems. The cases investigated so far were taken from automotive industry, brewery, and machine building. When presented with the design of the work systems, participants were encouraged to discuss these solutions, using their own ideas and questions as well as the leading questions from the matrix. Besides asking questions, the participants also suggested improvements to the solutions presented. As a special feature of the workshop, artists trained in Graphic Recording were present to turn the participants' ideas into visual presentations of improved design solutions. In this chapter, the method is described in detail, and recommendations for future applications and further developments are given. The approach, obviously, addresses all facets of the digital sovereignty matrix in a holistic analysis and design methodology.

New Digital Work is embedded in a broader digital transformation process affecting national economies and societies as well as global cooperation and competition. The next two chapters to be discussed here refer to these encompassing transformation processes.

Over the past decades, globalization has continuously increased, supported by advanced digital communication and production technologies, leading to integrated global supply chains. Thorsten Lammers, Matthias Guertler, Nathalie Sick, and Jochen Deuse (Lammers et al. 2023, this volume) consider Australia's position in this context.

In Australia, due to its remote geographic location and specific socioeconomic conditions, globalization has resulted in a loss of domestic manufacturing capabilities. With recent changes in the geopolitical environment (trade wars, actual wars, Covid-19, climate crisis, etc.) local production is becoming more attractive. The authors explore the potential of digital technologies to improve Australia's capabilities for reshoring manufacturing. Findings indicate that a highly skilled digital workforce is needed to leverage the country's potential in world-leading niche manufacturing. The Associate Degree of Advanced Manufacturing, developed and delivered by the Centre for Advanced Manufacturing at the University of Technology Sydney (UTS), is presented as an example of how to upskill the manufacturing workforce.

East Asia – and the neighboring Pacific and South East Asian regions – is a very large and diverse region, including frontier, emerging, and developed markets, among them worldwide leading economies in terms of digital transformation. Min-Ren Yan, Alexandra Shajek, and Ernst Hartmann give an overview of the situation regarding New Digital Work in the region and provide an in-depth analysis of developments in Taiwan (Yan et al. 2023, this volume). Issues relevant across East Asia – in different forms for the individual countries, but important for all – include occupational health, and gender inequalities when it comes to labor market participation and career development.

An important factor of digital transformation in Asia is the emergence of digital labor platforms, affecting especially India, the Philippines, and Pakistan in terms of inflow of work and earnings from abroad, via freelance platforms. The People's Republic of China is one of the world's largest platform economies, and labor platforms have been actively promoted by the government and media. There is some concern regarding the working and contract conditions, and workers' rights, within digital platform work (ILO – International Labour Organization 2018, 2021).

In Taiwan, as a leading technology developer and manufacturer, especially in the semiconductor branch, the government has been busy providing conducive conditions for Taiwan to keep its competitive edge. In inter-departmental cooperation, programs have been implemented addressing the development of AI talents, international cooperation in AI research, fostering startup foundations, and academia-industry cooperation, especially with respect to SMEs.

A final contribution to this volume gives a critical reflection on the notion of digital sovereignty itself. The concept of digital sovereignty may be (mis-)understood as an approach to 'make things simple', to generate environments where humans may act as they like, and always achieve the results they wanted and predicted, by employing simple, clear, and straightforward actions. (Un-)fortunately, the world is not like this. As Thomas Mühlbradt (Mühlbradt, 2023, this volume) points out, sociotechnical systems are inherently complex systems, at least most of them. As a prototypical example of complex sociotechnical systems, he considers work in the healthcare system. One consequence of this complexity is that appropriate methods for analyzing, modeling, and designing – or better: developing – sociotechnical systems will always preserve this complexity in some way, thus not yielding very neat and simple results, but rather results that require some effort to (fully) understand and put into context and practice. In fact, the results yielded by the digital sovereignty matrix as shown in Fig. 1 (Pentenrieder et al. 2023, this volume) are rather complex, but domain experts seem to like this quality, because it gives them the information they need to understand what is the situation in a given case. Conversely, these experts would rather be worried by approaches they would feel to be overly simplistic or reductionist.

As a second consequence, digital sovereignty in complex sociotechnical systems also requires complex competences, abilities to deal with dynamic, semi-intransparent, ambiguous situations. Thomas Mühlbradt gives an example of how these competences may be developed, by demonstrating modules from the Master of Science in Industrial and Organizational Psychology program at FOM University of Applied Science (based in Essen, North Rhine-Westphalia, Germany).

7 Concluding Remarks

Within the concluding remarks to an introduction chapter of an edited volume, it might be appropriate to give some background information on the history of this collaborative publication, of where all this came from, and how it was brought about.

Since early in the 2010–2020 decade, the Institute for Innovation + Technology (iit, Berlin, Germany) has been involved in accompanying research in the context of research and development programs in the domain of Industry 4.0, funded by the German Federal Ministry of Economic Affairs and Climate Action (abbreviated BMWK, formerly BMWi). During this research, it became evident that the future of work would be a topic of outstanding public, political, and scientific interest, and that this issue should be addressed by the accompanying research, and also by the individual R&D projects, in their respective contexts. To start this discourse, a small-group, informal expert talk was organized, bringing together participants from industry – automotive, machine components, robotics, logistic systems – with researchers from Mechanical Engineering/Production Systems, Ergonomics/Work Psychology, Electronics and Communications Engineering, Industrial Sociology, and Computer Science. This discussion was very fruitful and it was decided to elaborate on the contents by making up a common publication on the future of work in Industry 4.0, which was published in German as a printed as well as an open access online publication (Botthof and Hartmann 2015), and turned out to become one of the most accessed among all of Springer's open-access publications (with more than 1.8 million accesses; November 2022).

A second volume followed (Wischmann and Hartmann 2018), providing practical examples of how the R&D projects took up these impulses in their research and development activities.

For quite a while it was discussed how a further publication in this line should look like. The final decision was: It should take up the core philosophy of the successful 2015 publication, but with major content updates, with a broader perspective beyond Germany, and in English.

Seven authors from the two former volumes – namely Liane Bächler, Hauke Behrendt, Jochen Deuse, Ernst Hartmann, Jivka Ovtcharova, Thomas Mühlbradt, and Roman Senderek – contribute again to this volume. The other authors are colleagues involved in research and discourses with one or the other of the former authors and editors.

Another relevant context for this publication is iit's project 'Digital Sovereignty in the Economy', funded by Dr. Johannes Heidenhain GmbH, a leading provider of industrial measurement devices and controllers for CNC machine tools. This project is explicitly not designed to provide individual services for Heidenhain, its goal is rather to stimulate a broad discussion on digital sovereignty in the economy, taking enterprises as well as employees into account. Regarding all content-related and scientific issues, iit operates within this project autonomously, without control or guidance by Heidenhain. Within this project, iit performs analyses on workplace and company level, a group of junior scientists/PhD candidates is supported in their research, symposia are organized, and edited books are published. Two of these books are already available (Hartmann 2021b, 2022b), the third one is the present volume. A fourth volume, addressing digital sovereignty on the company level, is planned for 2023, and will also be published in English.

Thus, this volume combines two lines of tradition. A relatively broad range of topics and global regions is addressed, by authors from a variety of academic disciplines. As described in the previous sections of this chapter, the contributions cover the domain of digital sovereignty at the workplace rather comprehensively, focusing on specific aspects for each sub-domain.

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Measuring the Impact of Artificial Intelligence and Robotics on the Workplace

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Abstract. Understanding how AI and robotics impact the workplace is fundamental for understanding the broader impact of these technologies on the economy and society. It can also help in developing realistic scenarios about how jobs and skill demand will be redefined in the next decades and how education systems should evolve in response. This chapter provides a literature review of studies that aim at measuring the extent to which AI and robotics can automate work. The chapter presents five assessment approaches: 1) an approach that focuses on occupational tasks and analyzes whether these tasks can be automated; 2) an approach that draws on information from patents to assess computer capabilities; 3) indicators that use AI-related job postings as a proxy for AI deployment in firms; 4) measures relying on benchmarks from computer science; 5) and an approach that compares computer capabilities to human skills using standardized tests developed for humans. The chapter discusses the differences between these measurement approaches and assesses their strengths and weaknesses. It concludes by formulating recommendations for future work.

Keywords: AI and robotics · Assessment · Automation

1 Introduction

In the past, three major technological breakthroughs have ushered in industrial revolutions by enabling mass production, accelerating growth and shifting employment from agriculture to manufacturing and later to services: the introduction of steam-powered mechanical manufacturing in the 18th century; the progress in electrical engineering in the 19th century; and the invention of the computer in the 20th century. It is widely believed that artificial intelligence and robotics (in the following AI) resemble these

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technologies in their potential to transform work and the economy. Like these technologies, AI and robotics are seen as "general-purpose technologies" that are applicable in different economic sectors and can raise productivity across vast parts of the economy [7]. Therefore, they may trigger a Fourth Industrial Revolution in the 21st century.

While there is general agreement that AI will transform the economy, the direction of this transformation is still less clear. On the one hand, these technologies may lead to technological unemployment by replacing workers at the workplace. On the other hand, they can complement and augment workers' capabilities and, with that, raise productivity, create new jobs and boost new demand for labor. To unravel this impact, studies must first understand what AI and robotics can and cannot do. Knowing which AI and robotics capabilities are now available and how they relate to human skills can shed light on the work tasks that these technologies can overtake from humans and the extent to which they can automate jobs in the future.

This chapter provides an overview of different methodological approaches to assessing the impact of AI and robotics on the workplace. These approaches aim at quantifying the degree to which occupations can be carried out by machines. Most of them stem from the social sciences and economics, but there are also important contributions from cognitive psychology and computer science. Some of this work has an exclusive focus on AI and robotics, e.g. [8, 12, 16]. Other studies view these technologies as part of a more general process of technological advancement, e.g. [4, 13].

Measuring the impact of AI on the workplace is fundamental for understanding its broader impact on the economy and society. It also helps in developing realistic scenarios about how jobs and skill demand will be redefined in the next decades. This should enable policy makers to adjust education and labor market systems to the challenges to come and to prepare today's students and workers for the future.

The chapter proceeds as follows. The subsequent sections present five methodological approaches for assessing the impact of AI and robotics on work (Sects. 2, 3, 4, 5 and 6): a task-based approach; an approach that draws on information from patents; indicators based on AI-related job postings; measures relying on benchmarks; and a skills-based approach. The chapter discusses the differences between these measurement approaches and assesses their strengths and weaknesses (Sect. 7). It concludes by formulating recommendations for future work (Sect. 8).

2 The Task-Based Approach

In analyzing the extent to which AI can displace workers, many economic studies follow a so-called "task-based" approach: they focus on occupations and their corresponding tasks and analyze whether these tasks can be automated. This way they quantify the share of tasks within an occupation that can be performed by computers. This analysis typically relies on expert judgement or, sometimes, on the authors' own notion of what tasks computers can perform. The main goal of this literature is to assess the impact of automation on the economy. To this end, studies map the information on occupations' automatability to micro-level labor market data and study employment and wage levels in occupations and industries at high risk of automation.

The "task-based" approach has its origin in the work of Autor, Levy and Murnane [4]. The authors make the assumption that computers can replace workers in routine cognitive and manual tasks. The reason is that these tasks follow exact repetitive procedures that can be easily codified. By contrast, non-routine tasks are assumed hard to formalize and automate because they are more tacit and inexplicable. To measure automatability, Autor, Levy and Murnane [4] use several variables from the U. S. Department of Labor's Dictionary of Occupational Titles (DOT) taxonomy. They categorize tasks that require direction, control, and planning of activities, or quantitative reasoning as non-routine and, thus, non-automatable. Tasks that require workers to precisely follow set limits, tolerances, or standards, or tasks that involve finger dexterity are labelled as manual and, thus, automatable.

Autor, Levy and Murnane [4] use their measures to explain changes in labor demand over time. They hypothesize that, as technology gets cheaper, employers would increasingly replace workers in routine tasks with machines. At the same time, the demand for workers in non-routine tasks would raise, because, according to the model, the computerization of the workplace increases the demand for problem-solving, analytical and managerial tasks.

Frey and Osborne's study [13] extends the approach of Autor, Levy and Murnane [4] to account for more recent technological advancements that have expanded the potential for work automation. Progress in AI and machine learning, in particular, has enabled the automation of many non-routine tasks, such as translation, disease diagnosing and driving, that were seen as 'uncodifiable' in the Autor, Levy and Murnane's framework.

Frey and Osborne's [13] methodological approach to measure the automatability of the workplace follows three major steps:

- First, the authors define three types of work tasks that are *not* yet automatable: perception and manipulation tasks, such as interacting with objects in unstructured environments; creative intelligence tasks, such as developing novel ideas; and social intelligence tasks, such as negotiating. Frey and Osborne [13] operationalize these so-called bottlenecks to automation with O*NET, a widely used occupation taxonomy that systematically links occupations to tasks. Concretely, they draw on nine task-related variables from O*NET: the degree to which an occupation requires finger dexterity, manual dexterity and working in cramped spaces (as proxy for perception and manipulation tasks); the degree to which occupations require originality and knowledge of fine arts (as proxy for creative intelligence); and the extent to which occupations involve social perceptiveness, negotiation, persuasion, or assisting and caring for others (as measurements for social intelligence).
- Second, Frey and Osborne [13] assess the automatability of 70 of the 700 occupations in the O*NET database by drawing on expert judgment. Specifically, the authors provided computer experts with task descriptions of occupations in O*NET and asked them to classify occupations as either automatable or non-automatable based on this information.
- Third, the automatability of occupations derived from the expert assessments is modelled as a function of the nine O*NET variables that measure the bottlenecks to automation. The obtained estimates are used to predict the probability of automation of all 700 occupations in O*NET.

The studies of Arntz, Gregory and Zierahn [3] and Nedelkoska and Quintini [19] introduce important improvements in Frey and Osborne's approach. Instead of estimating the risk of automation at the level of occupations, they estimate the automatability of individual jobs. This accounts for the fact that jobs within the same occupation may differ in their task mix and, hence, in their proneness to automation. More precisely, the studies map the expert ratings on automatability from the Frey and Osborne's study [13] to micro-level data of the Survey of Adult Skills of the Programme for the International Assessment of Adult Competencies (PIAAC). The PIAAC data provides detailed information on the tasks that individuals perform in their jobs. The studies use this information to estimate the relationship between individual-level job tasks and automatablity for the 70 occupations initially assessed by the experts. They then use the estimated parameters to infer the probability of automation of all jobs in the PIAAC sample.

Following this revised approach, the two studies estimate much smaller shares of jobs prone to automation than suggested by Frey and Osborne [13]. Arntz, Gregory and Zierahn [3] find that 9% of jobs in the United States are highly automatable, as opposed to a share of 47% estimated by Frey and Osborne [13]. Nedelkoska and Quintini [19] show that 14% of jobs in the economies represented in PIAAC are at high risk of automation.

Other studies develop alternative task-based measures. Brynjolfsson, Mitchell and Rock [8], for example, develop a rubric for assessing task automatability. The rubric contains approximately 20 task characteristics that make a task more or less suitable for machine learning. These characteristics include, for example, the need for complex, abstract reasoning for solving the task, or the availability of immediate feedback on how successfully the task was completed. The authors let crowdworkers rate 2,069 work activities in O*NET with the rubric and map the scores to the corresponding occupations. This way they derive a measure of occupations' suitability to machine learning. The authors find that this measure is only weakly correlated with wages.

3 Assessing Automation Through the Content of Patents

A number of studies draw on information from patents to determine what new technologies can and cannot do in the workplace. The text of patents provides, namely, detailed descriptions of technologies and their capabilities. Studies typically link this information to occupational descriptions from taxonomies such as O*NET to determine the extent to which the patented technologies are applicable in the workplace. This analysis usually relies on natural language processing techniques to detect whether patent texts indicate the workplace applicability of the technologies and to determine their textual similarity to occupational descriptions.

The study of Webb [26] develops a patent-based approach to study the exposure of occupations to computer software applications, industrial robots and AI. It draws on patents from the Google Patents Public Data by IFI CLAIMS Patent Services and links them to task descriptions of occupations provided in O*NET. The study builds this linkage in several methodological steps.

First, Webb [26] identifies patents of the three technologies of interest by searching the entire patent database for particular keywords in the patent titles and descriptions. For example, patents of AI technology are sorted out through keywords such as "neural network" and "machine learning". Webb [26] then extracts all verb-noun pairs from the patent titles in these subsets of patents (e.g., diagnose, disease). The verb-noun pairs are used to indicate the tasks that the patented technology is intended to address. To determine the prevalence of technologies addressing a particular task, the frequency of occurrence of each verb-noun pair (and pairs similar to it) is calculated. For example, 0.1% of the AI patents may contain the pair "diagnose, disease" (or similar pairs) in their title.

Second, Webb [26] turns to the task descriptions of occupations and applies a similar natural language processing technique to extract the verb-noun pairs from those. He then assigns to each pair the relative frequency score estimated in the patent analysis. For example, the occupation "medical doctor" contains the task "diagnose patient's condition", from which the verb-noun pair "diagnose, condition" is extracted. When analyzing the impact of AI on occupations, this pair receives the score 0.001 because it is addressed by 0.1% of the AI patents.

Third, Webb [26] aggregates the tasks to the occupation level to obtain a measure of occupations' exposure to automation. In O*NET, occupations are linked to a set of tasks and information is provided about the relevance of each task for the occupation. Webb [26] averages the scores of tasks across occupations by weighting the tasks by their importance for an occupation.

The results show that jobs occupied by low-skilled workers and low-wage jobs are most exposed to robotic technologies, while jobs held by college-educated workers are most exposed to AI. In addition, increases in occupations' susceptibility for robotic technologies are linked to declines in employment and wages.

Montobbio and colleagues [17, 18] develop an approach for quantifying automation that relies on patents of robots. The goal is to identify robotic technologies that explicitly aim at replacing workers in the workplace [18] and to determine the exposure of occupations to such innovations [17]. The empirical analysis contains several methodological steps.

In a first study, Montobbio and colleagues [18] develop an approach for identifying labor-saving robotic technologies. This analysis draws on all patents published between 2009 and 2018 by the United States Patent and Trade Mark Office. First, the authors select patents of robotic technologies by using patent codes available in the data that indicate robotic patents and by additionally scanning the patent texts in the entire database for the morphological root 'robot'. Second, the authors identify the labor-saving patents among the subset of robotic patents. This is achieved by analyzing the co-occurrence of certain verbs (e.g. 'reduce', 'save'), objects (e.g. 'worker', 'labor') and object attributes (e.g. 'task', 'hour') at the sentence level. Finally, they describe the set of human tasks that the labor-saving technologies aim at reproducing by using a probabilistic topic model. This natural language processing algorithm elicits in an unsupervised manner the semantic topics that occur in the patent texts of labor-saving robotic technologies.

In a second study, the authors draw a more direct link to occupations [17]. They use the robotic labor-saving patents identified by Montobbio et al. [18] and their corresponding CPC (Cooperative Patent Classification) codes. The CPC codes contain definitions of the technological content of patents. The authors quantify the textual proximity of these codes to task descriptions from O*NET using natural language processing techniques.

They then aggregate these similarity measures from the task to the occupation level, by taking into consideration the relevance of different tasks within an occupation. By linking the similarity measure to US labor market data, the authors show that the manufacturing sector is most exposed to automation. Furthermore, occupational exposure to labor-saving technology is negatively correlated with wage level in 2019 and wage growth in 1999–2019, as well as employment level and growth in the same period.

Squicciarini and Staccioli [23] adopt the methodology by Montobbio et al. [17, 18] to study automation and its impact on employment. They connect the measure of occupational exposure to labor-saving technologies with employment data from 31 OECD countries to study changes in employment within occupations at high risk of labor displacement. The study finds that low-skilled and blue-collar occupations are most exposed to labor-saving robotic technologies, but also analytic professions. However, there is no evidence of labor displacement, as employment shares in these occupations remain constant over time.

4 Using AI-Related Job Postings as an Indicator for the Use of AI in Firms

Another way to assess the use of AI in the workplace is to track the demand for AI experts in firms. The underlying assumption of this approach is that firms deploying AI technology also need workers with AI-related skills to manage and maintain this technology. Studies following this idea obtain information on firms' skills needs from job postings. The main source for such data is Burning Glass Technologies (BGT), a company that collects online vacancies daily and provides systematic information on their skill requirements, job title and occupation group. Studies link BGT data to firm-level data to study how AI deployment in firms, as proxied by the demand for AI skills in vacancies, is linked to wages, employment and growth.

Studies differ in the way they identify AI-related job postings. Squicciarini and Nachtigall [22], for example, scan job postings for a list of AI-related keywords. These keywords are obtained from the study of Baruffaldi et al. [6], who apply bibliometric analysis and text mining techniques on scientific publications, open source software and patents to assess developments if the field of AI. Four types of keywords are considered: generic terms, such as "artificial intelligence" and "machine learning"; approaches, such as "supervised learning" and "neural network"; applications, such as "image recognition"; and software and libraries, such as Keras and TensorFlow. To avoid over-identification, the authors categorize job postings as AI-related if they contain at least two keywords from different keyword groups. The study provides rich descriptive information on these job postings, among others, on their distribution across occupations and industrial sectors. It shows that the share of AI-related job postings increased considerably between 2012 and 2018 in the four observed countries Canada, Singapore, United States and United Kingdom. Such postings appear in all sectors of the economy, most frequently in the sectors "Information and Communication", "Financial and Insurance Activities" and "Professional, Scientific and Technical Activities".

Using BGT data, the studies of Acemoglu et al. [1] and Alekseeva et al. [2] adopt a similar approach to measuring AI activity in firms. Acemoglu et al. [1] classify firms as AI-adopting if their vacancies contain at least one keyword from a simple list of AI-related skills. The study links this measure to indicators of AI exposure and shows that firms that involve tasks at a high risk of automation, as identified by the indicators of Webb [26] and Felten, Raj and Seamans [12] (see below), are more likely to deploy AI, as measured by the demand for AI skills in job postings.

Similarly, the study of Alekseeva et al. [2] scans job postings from the BGT data for particular skills. These skills were identified as AI-related by Burning Glass Technology and refer to the knowledge of AI (e.g. machine vision) or to AI-related software (e.g. Pybrain, Nd4J). The study shows that the number of job postings that demand AI-related skills have considerably increased in the US economy over the last ten years. The study also find a wage premium for such vacancies.

By contrast, Babina and colleagues [5] use a skills-similarity approach to determine the AI-relatedness of job postings. Instead of pre-specifying keywords relevant for AI, the authors measure how frequently the skills contained in BGT job postings co-occur with four core AI terms: “artificial intelligence”, “machine learning”, “natural language processing” and “computer vision”. From this co-occurrence frequency they build a measure of AI-relatedness for each skill contained in the data, assuming that skills that often appear in vacancies containing the core AI terms are strongly related to AI. Subsequently, the authors estimate the AI-relatedness of job postings by averaging the AI-relatedness of all skills required in a posting. In contrast to previous studies using a binary classification of AI- and non-AI-related vacancies, this measure is continuous, allowing it to distinguish between jobs requiring more or less AI-related skills (e.g. deep learning vs. information retrieval).

In addition, Babina et al. [5] estimate the AI-relatedness of employees’ resumes obtained from data from Cognism Inc. This way the authors use both the demand and the existing stock of AI skills in firms to approximate AI deployment. Concretely, the authors search the resume data for terms that obtained high AI-relatedness scores in the analysis of job postings. This enables them to classify AI workers in firms. In a final step, Babina et al. [5] map both the job postings data and the resume data to firm-level data to study the characteristics of firms deploying AI and the effects of AI deployment on sales, employment and the market share of firms. The study shows that larger firms with higher sales, markups and cash holdings are more likely to deploy AI. In addition, the measure of AI deployment is positively linked to firm growth, both in sales and employment.

5 AI Measures Relying on Benchmarks

In computer science, the performance of AI and robotic systems are measured with so-called benchmarks. A benchmark is a task or a set of tasks that has been explicitly designed to evaluate the performance of a system. Typically, a benchmark provides training data, which the system uses to learn the task; a test dataset on which the task is performed; an evaluation framework and continuous numerical feedback to rate the system’s performance on the task [24]. The purpose is to compare different systems against the same benchmark test. Often, the performance of systems is compared to human performance on the benchmark.

There have been efforts to assess more systematically the state of the art of AI technology using information from benchmarks. Stanford University's AI Index Report, for example, collects and tracks leading benchmarks to assess the technical performance of AI in different domains, such as computer vision, language, speech recognition and reinforcement learning [27]. Other studies concentrate on single domains, such as the overview of natural language inference benchmarks by Storks, Gao and Chai [24].

Some studies connect the information on AI capabilities contained in benchmarks to information on the content of occupations in order to assess how progress in AI can impact the workplace. Martínez-Plumed et al. [16] and Tolan et al. [25] collect information on 328 different AI benchmarks. Instead of looking at AI performance on these benchmarks, the studies use the research output related to each benchmark (e.g., research publications, news, blog-entries) as a proxy for AI progress and its future direction. The reason is that benchmarks use different performance metrics, which makes it difficult to compare AI performance on different tasks and in different domains. The studies connect developments in AI research to occupations by using cognitive abilities as an intermediate layer. Concretely, they connect AI benchmarks to cognitive abilities and then connect cognitive abilities to work tasks. The authors argue that mapping the information from benchmarks to occupations by way of cognitive abilities is a promising approach since it indicates the broader ability domains in which the use of AI in the workplace is advancing and, conversely, the key abilities that technology cannot yet achieve. For occupational tasks, the studies derive 59 key work tasks linked to 119 occupations from two labor force surveys—the European Working Conditions Survey (EWCS) and the OECD Survey of Adult Skills (PIAAC)—as well as from the O*NET database. For the intermediate layer of cognitive abilities, they use a taxonomy of 14 cognitive abilities (e.g., visual processing, navigation, communication) inspired by work in psychology, animal cognition and AI. The results suggest relatively high AI exposure for high-income occupations and low AI impact on low-income occupations, such as drivers or cleaners.

The study of Felten, Raj and Seamans [12] is another attempt to link AI capabilities assessed through benchmarks to abilities and skills required at the workplace. The authors use AI evaluation results across nine major AI application domains made available by the AI Progress Measurement project of the Electronic Frontier Foundation (EFF). They re-scale the metrics in each domain to make them comparable and calculate the average rate of progress in each domain for the period 2010 to 2015. The advancements in each AI application domain are then linked to 52 abilities required in the workplace from O*NET. O*NET provides information on the importance and the prevalence of each ability within occupations. For each AI application domain, the authors ask 200 gig workers on a freelancing platform to rate the relatedness between the domain and the 52 abilities. In total, 1,800 persons were surveyed. By linking the abilities to occupations, the authors assess the extent to which occupations are exposed to AI, a measure they call AI Occupational Impact (AIOI). They find that it is positively linked to wage growth, but not to employment.

6 A Skill-Based Approach

Another approach to measuring the impact of AI on work is to compare the capabilities of AI to the human skills required for work. Such a comparison directly addresses the question of whether AI can replace humans in the workplace. Moreover, it provides information about AI's impacts that extends beyond the definition of current occupations to cover more general issues, such as the design of new occupations and workplaces or the development of education and training programmes that prepare students for the future. The comparison of human and computer capabilities typically relies on tests developed for humans. In computer science, such tests are used as benchmarks, on which the performance of systems is evaluated. Other work draws on expert judgement from AI researchers to determine whether state-of-the-art systems are capable of carrying out tests and tasks developed for humans.

Computer scientists have used different types of human tests to evaluate the capabilities of AI. Several examples should illustrate this since the full list of studies is long. Liu et al. [15] evaluate AI systems on IQ tests for humans. The authors construct a comprehensive dataset containing 10,000 IQ test questions by manually collecting them from books, websites and other sources. They test different systems on different subsets of questions, i.e. questions related to finding an analogical word given other words or finding the correct number given a sequence of numbers. Similarly, Ohlson et al. [20] test the ConceptNet 4 AI system on the Verbal IQ part of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III). DeepMind, an AI-focused company owned by Google, famously evaluated the performance of state-of-the-art NLP systems on 40 questions from mathematics exams for 16 years old British schoolchildren [21]. Clark et al. [10] tested their ARISTO system on the Grade 8 New York Regents Science Exam.

Some computer scientists have argued that standardized tests are useful for measuring AI progress and stimulating AI research. According to Clark and Etzioni [9], standardized tests are suitable evaluation tools because "they are accessible, easily comprehensible, clearly measurable, and offer a graduated progression from simple tasks to those requiring deep understanding of the world" [9: 4]. Moreover, they can address a wide range of AI capabilities. Liu et al. [15] note that IQ tests assess systems in different areas, such as knowledge representation and reasoning, machine learning, natural language processing and image understanding.

Outside of computer science, Elliott [11] assesses AI capabilities with the OECD Survey of Adult Skills (PIAAC) by drawing on expert judgment. PIAAC is designed to measure literacy, numeracy and problem-solving skills of adults. The questions are presented in different formats, including pictures, texts and numbers. They are designed to resemble real-life tasks in work and personal life, such as handling money and budgets, managing schedules, or reading and interpreting statistical messages and graphs presented in the media. Elliott [11] asks 11 computer experts to rate the capabilities of AI of solving the PIAAC items. The results of these ratings are presented separately for questions of varying difficulty and allow for comparing AI to humans at different proficiency levels.

The study shows that, according to the interviewed computer experts, in 2016, successful performance of AI on literacy was expected to range from 90% on the easiest questions to 41% on the most difficult questions [11]. This roughly resembles the scores of low-performing adults on the literacy test. In numeracy, AI performance, as estimated by experts, ranged from 66% on the easiest to 52% on the hardest questions. This is below average human-level performance on the simplest numeracy tasks and beyond average human scores on the hardest tasks.

The study of Elliott [11] served as a stepping stone to a bigger project aimed at assessing AI at the Centre for Educational Research and Innovation (CERI) at the OECD. The AI and the Future of Skills project aims at comparing AI and human capabilities across the full range of skills needed in the workplace.[1] To this end, the project is developing an approach using a battery of different tests. For example, key cognitive skills will be addressed with education tests such as PIAAC and the Programme for International Student Assessment (PISA), while occupation-specific skills will be assessed with tests from vocational education and training that provide certification or license for specific occupations. In addition, tests from the fields of animal cognition and child development will be used to assess basic low-level skills that all healthy adult humans, but not necessarily AI, have (e.g., spatial memory, episodic memory and common sense for the physics of objects).

7 Strengths and Weaknesses of the Different Approaches

Existing approaches to assessing the impact of AI and robotics on employment and work have mostly focused on whether these technologies can automate tasks within occupations; whether they can reproduce human skills required in jobs; and whether they are reflected in the human capital investments firms make. Studies have used innovative methods and data to answer these questions. However, some gaps in the methodology remain. In the following, some strengths and weaknesses of the five approaches are discussed without the claim of comprehensiveness or the attempt to elevate one approach against the other.

The Task-Based Approach. The task-based approach has sparked off much research. The reason, perhaps, is that it offers a convenient way to quantify the potential for automation in occupations and in the economy. This is made possible through the use of O*NET, a comprehensive taxonomy of occupations that provides systematic information on task content and allows mapping to labor market surveys to study the empirical distribution of occupations. However, although this research heavily relies on expert judgments of AI capabilities with respect to occupational tasks, it leaves the process of collecting these judgements less transparent, with the available studies not providing sufficient information on the selection of experts, the methodology used for expert knowledge elicitation or the rating process. Moreover, experts rate the capabilities of AI and robotics with regard to very broad descriptions of occupational tasks provided in O*NET (e.g., “Bringing people together and trying to reconcile differences”).

The Patent-Based Approach. Linking patents to occupations with NLP techniques is an innovative way to assess the impact of technology on work, both in terms of the data and the method used. Like the task-based approach, this approach is convenient for

[1] www.oecd.org/education/ceri/future-of-skills.htm

quantifying the impact of AI in the economy. However, as Webb [26] and Georgieff and Hyee [14] note, the approach focuses on innovative efforts with regard to AI that have been described in patents rather than actual deployment of AI in the workplace. With that, the patent-based approach is an assessment of the *potential* impact of technology on work. At the same time, the approach may miss innovations that are not described in patents.

The Job-Postings-Based Approach. In contrast to the patent-based approach, but also the task-based approach, which measure the potential for automation of occupations, indicators that rely on job postings aim at capturing the actual deployment of AI in firms. Moreover, they aim at providing a timely tracking of AI adoption by using up-to-date data on the demand for AI skills across the labor market. However, these measures rely on the strong assumptions that all companies that automate their work processes recruit workers with AI skills and, *vice versa*, that all companies that employ AI specialists are doing so to automate their own tasks. Georgieff and Hyee [14] point to several realistic scenarios that violate these assumptions. For example, AI-using firms may train their workers in AI rather than recruit new workers with AI skills. Or they may decide to outsource AI support and development to specialized firms. In addition, the use of some AI systems may not require specialized AI skills. Furthermore, indicators based on job postings can capture the use of AI at the firm level, but not at the level of concrete work tasks or occupations. For example, a company may recruit IT specialists with AI skills in order to automate routine manual tasks in production.

The Benchmarks-Based Approach. Benchmarks offer an objective measure of AI capabilities since they evaluate the actual performance of current state-of-the-art systems. The problem of using benchmarks to measure AI's impact on the workplace is that they do not systematically cover the whole range of tasks and skills relevant for work. To our knowledge, there has not been an attempt to systemize the information from benchmarks according to a taxonomy of work tasks or work skills in order to comprehensively assess the capabilities of AI and robotics. Studies that link information from benchmarks to occupations offer a promising way to measure the automatability of the workplace. However, they share some of the methodological problems of the task-based approach. Specifically, occupational tasks and abilities are crudely described and their relatedness to AI is assessed through subjective judgments.

The Skills-Based Approach. The skills-based approach uses human tests to compare computer and human capabilities. The reference to humans is key to understanding which human skills are reproducible by AI and robotics, and which skills can be usefully complemented or augmented by machines. This can help design new jobs in future that make the best use of both humans and machines. Moreover, it helps answer additional questions related to skills supply: Which skills are hard to automate and, thus, worth investing in in future? What education and training can help most people develop work-related skills that are beyond the capacity of AI and robotics?

However, using human tests on AI and robotics bears some challenges. One challenge, also common for other benchmark tests, is overfitting. It means that a system can excel on a test without being able to perform other tasks that are slightly different from the test tasks. This is still typical for AI systems as they are generally ‘narrow’, e.g. able to perform very specific tasks. Another challenge comes from the fact that human tests are designed for humans and, thus, take for granted skills that all humans share. Since such skills cannot be assumed for AI, human tests can have different implications for humans and machines. For example, the simple task to count the objects in a picture tests humans’ ability to count, whereas, for AI, it is also a test for vision and object recognition.

8 Conclusion

Assessing AI and robotic capabilities is a necessary foundation for understanding the impact of these technologies on work and employment. Existing assessment approaches address different aspects of the relationship between technology and work, and have different implications for policy. The task-based and the patent-based approaches assess the automatability of tasks within occupations. The focus of these approaches is more on quantifying the potential of AI and robotics to automate the economy than on developing a comprehensive measure of what computers can and cannot do. By contrast, benchmarks provide information on the technical performance on AI by objectively evaluating the capabilities of current state-of-the-art systems. The job-postings approach sheds light on another important aspect of the use of AI and robotics in the workplace: the extent to which firms need AI skills, the type of AI skills they need, and the characteristics of firms that are linked to AI skills needs. Finally, the skills-based approach provides a useful comparison to human skills that provides information not only about the impact of AI on work, but also about how education should evolve in response.

A systematic assessment of AI and robotics requires a comprehensive framework that brings together different assessment approaches. Such a framework should…:

1) *Make use of different disciplines as they provide different perspectives and opportunities for understanding AI and robotics capabilities.*

Concretely, computer science can provide useful ways to measuring AI and robotics capabilities. Approaches from the social sciences and economics are useful for linking these capabilities to occupations and assessing their impact on the economy and the society. Psychology and psychometrics can help linking measures of human abilities to AI and robotics.

2) *Provide a comparison to human skills.*

As noted above, a reference to human skills would make it possible to compare the technical performance of AI and robotics to the proficiency with which humans carry out tasks in their jobs. This will provide information to help understand how AI and robotics will change the demand for skills and how policies should shape skills supply in order to respond to these changes.

3) *Use comprehensive tasks and skills taxonomies to guide the assessment of AI and robotics skills.*

A comprehensive assessment of AI and robotics capabilities should cover the full range of tasks that appear in work, all relevant human skills as well as capabilities that are non-trivial for machines, but commonplace for humans. Such an assessment should focus not only on the capabilities and tasks that AI and robotics can achieve, but also on the stumble blocks to automation.

4) *Include benchmarks and evaluations from AI research.*

A multitude of benchmarks and evaluations already assess AI and robotic systems empirically. However, these have not been systematically classified into a taxonomy of skills or tasks. Populating comprehensive skills and tasks taxonomies with information from such assessments would be an important component of any systematic measure of AI and robotics.

5) *Use expert judgement in a way that is transparent and meets established scientific standards.*

Where benchmarks are lacking, expert judgment can provide important insights into the capabilities of AI and robotics. However, expert judgment should be elicited with care. Specifically, the choice of experts should be substantiated; computer capabilities should be rated with respect to standardized and detailed tasks; the degree of agreement between experts should be reported; and the aggregation of individual experts' ratings should be explained.

A multidisciplinary approach that combines complementary methodologies, draws links to both work tasks and human skills, and uses standardized assessment instruments will provide valid and reliable measures of AI and robotics. Such an approach would also provide measures that are meaningful for the policy community.

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Digital Work in Smart Production Systems

Changes and Challenges in Manufacturing Planning and Operations

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Abstract. On the one hand, Industry 4.0 provides possibilities to address arising challenges such as globalisation, individualisation and shortening product lifecycles. On the other hand, it also increases changes and challenges in planning and operation processes of production systems.

The paper discusses the changes in digital work in the areas of planning, operating and improving smart production systems. Current research approaches show that especially in planning processes and supportive tasks a high dynamic is evident, but also the work on the shop floor is changing. Automation technology and intelligent algorithms as a base for production planning and control up to factory-as-a-service concepts reduce operational room for manual actions, but require new digital planning, implementation and maintenance tasks. Furthermore, technologies like cobots enable new forms of flexible coexistence between human and machine in production systems. Due to the increasing complexity of products and production systems, conventional improvement approaches from the fields of Lean Management and Six Sigma are reaching their limits, as the analyses are often limited to simple relationships and correlations. Data science in the industrial environment enables new opportunities to analyse large volumes of data to identify multivariate patterns and correlations. All of this leads to new requirements for competences, roles and work organisation.

Keywords: Manufacturing · Smart production systems · Industry 4.0 · Internet of Things

1 Introduction

Production Systems are ever-changing, adapting to the market, circumstances and newly available technologies. In the last decades, globalisation and individualisation have changed the planning and operating of production systems, increasing the number of

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product variants and shortening product lifecycles. Therefore, industrial companies are forced to shorten planning processes and to be more flexible in their production. As a result, production systems are changing from complicated to complex systems [1]. Technologies often associated with Industry 4.0 such as smart automation based on Cyber-Physical Systems (CPS), the Internet of Things (IoT), and Artificial Intelligence (AI) [2] can help to handle the resulting complexity, but create new challenges, especially concerning organisational and human aspects. The following paper will analyse challenges and changes along the product lifecycle and illuminate work in Smart Production Systems.

The term "Smart Production Systems" is always connected, sometimes even used synonymously, with CPS and Industry 4.0. The term Industry 4.0 was first shaped in 2011 as part of the high-tech strategy in Germany marking the beginning of the fourth industrial revolution [3]. Each preceding industrial revolution has brought radical changes. The first industrial revolution at the end of the 18th century enabled industrial production in factories based on water and steam power. The second revolution using electrification to enable mass production started at the end of the 19th century. In the 1970s, the third revolution was driven by the introduction of electronics and Information and Communication Technologies to automate production [1, 2]. Each of the revolutions not only brought technological change but also changed production systems with all aspects including organisational and human factors fundamentally [4]. The first revolution completely changed society from producing at home and in small workshops to the production in factories creating a new working class. The introduction of Scientific Management and work division in the second revolution has changed work until today. The following revolution due to the automation of processes changed work adding more surveillance tasks and requiring a more systematic approach [5].

Currently, the term Industry 4.0 characterizes the emergence and usage of new digital technologies in industrial production, including (Fig. 1): Big Data and Analytics, Autonomous Robots, Simulation, Horizontal and Vertical Integration, IoT, Cybersecurity, Cloud Computing, Additive Manufacturing and Augmented Reality [6, 7].

The goal of Big Data is to ensure real-time decision-making and finding patterns in a large amount of data from different sources to optimise production. Although robots have long been used in manufacturing, they are becoming more cooperative, flexible and autonomous, interacting with each other and with humans [6, 8]. Simulation will be used more extensively and can access real-time data to perform more efficient testing so that processes and settings can be improved and optimised before production starts. Therefore, it can help to reduce a waste of time and improve product quality [9]. The Horizontal and Vertical System Integration seeks to connect the entire organisation including all departments and functions as well as to integrate suppliers and customers so that companies are able to interact and connect. IoT refers to objects such as sensors, smartphones, and any machines or devices that facilitate data transfer. In manufacturing, this is referred to as the Industrial Internet of Things (IIoT) [6]. With increasing connectivity, cybersecurity becomes more important because as networking increases, so does the security risk. The information systems and production lines are at increased risk of cyberattacks and companies need to protect their systems. The cloud is an important topic

Fig. 1. Technologies of Industry 4.0 (own illustration)

for the contribution of networked system integration to the transformation of Industry 4.0. The main goal here is to increase efficiency by lowering product lifecycle costs and achieving optimal resource utilisation by managing customer-oriented work with variable demand [9]. The next technology is additive manufacturing, which is mainly used for the production of small series of customised products. In the process, efficient, decentralised additive manufacturing systems reduce transport routes and inventories [6, 8]. The last technology describes augmented and virtual reality (AR & VR). AR tools support the integration of computer-based imaging of a real environment with additional and valuable information [10].

All the described technologies and especially a comprehensible combination of these technologies are essential to uncover new potentials in the product lifecycle. To realise this potential not only the technology is needed but also an adaption of organisational and human factors, therefore changing work as a whole. The following examples for the implementation of new technologies and the accompanying change of work are given in the context of recent research projects of the “Institute of Production Systems (IPS)” and the cooperating “RIF Institute for Research and Transfer e. V.”.

2 Digital Planning of Smart Production Systems

One part of the product lifecycle that Industry 4.0 is fundamentally changing is the planning of production systems. As described, not only production systems themselves but also the planning process become more complex because new technologies and requirements need to be considered and new competences and job profiles are required.

Furthermore, to keep pace, the organisation of the planning process itself is changing as outlined in the following sections.

2.1 Agile Planning Methods

The growth of the product and its process complexity combined with the cost pressure have placed well digitalised and organised companies ahead into success. With the goal to shorten the product development process (PDP), the product design and production system design needs to be paralleled for efficient time and cost. Simultaneous Engineering has been a helpful method to reduce the PDP, however, space for reconciliation is still present. While mature software systems (such as computer-aided x (CAx), product lifecycle management (PLM) systems, manufacturing execution systems (MES), etc.) are universal tools in design and production areas, isolated solutions remain in the task of production planning. The opportunity lies in connecting isolated solutions to a smart and holistic system.

In the product development process, established IT systems focus not only on end-to-end data management and distribution (e.g. PLM, ERP) but also on operational project management tasks, including the control of planning processes (e.g. time and resource planning, quality gates). In the field of data management, distribution, and use, neutral data exchange formats (e.g. JT, STEP, XML) have become established for uniform description and integration in the industrial context. The networking of services and products provide impulses for future planning approaches. For example, through end-to-end data management, the product development phase can be assessed, therefore evaluating the ergonomics and production time is possible at an early stage and can be considered for further planning initiatives. Moreover, as the data for digital design increases, production scenarios can be simulated beforehand using digital human models to ensure more robust planning. Therefore enabling structured data management will develop more consistent planning [11]. Current system landscapes show perceptible media discontinuities between the leading data-holding systems of product design, the process-oriented project management and collaborated solutions between companies. The challenge lies in creating a holistic dataset, combining and storing accessible knowledge. Putting forth a methodical system in organising new digital work can enhance the technological change and helps to overcome complex challenges [11, 12].

For companies to overcome current volatile markets, adaptability needs to be considered in the design of production systems. This requires that the possibility of redesigning systems comes at a low financial cost and operating the production system efficiently without additional resources [13]. Agile working methods help customer-oriented systems react swiftly to unpredictable and constant changes through distributive innovations [14]. At a micro level, the method aims to change the work processes, structures, and conditions to a time-saving, goal-oriented complex operation. Expected competences demand employees to adapt to their new availability and the production system's expanded accessibility [15].

The basis of digital, agile work is the formation of interdisciplinary teams characterised by removing barriers between different disciplines and their experts' collaboration [14]. Successful collaboration can be achieved when comprehensive transparency is presented at the base of the process. The "Backlog" is a communicative tool that provides overview information to keep all team members informed about all tasks at all times [14]. Simple digital tools to organise the work enhance the effects of agile methods. Digitalisation offers numerous approaches to automating workflows, simplifying interfaces, or increasing flexibility [16]. The characteristics of Digital Work are as follow: agility, spacious, voluntary-based, instructing leadership, high dynamic, short-cycle, and digitally supported [17]. The benefits that follow these characteristics are: better management of changing priorities, increase in productivity, faster development and delivery of products, more precise overview of projects, increase in transparency, and higher cooperation quality with the IT department in the company [18].

Digitalisation has been available for use for a decade already. However, it was not until COVID19 that many companies pushed themselves to set up the digital landscape. During the pandemic, collaboration software has helped to create a digital work environment for distributing the workload. Planning any kind of project, contrary to traditional ways, can be achieved regardless of the team members' location. Nevertheless, digitalisation also comes with an overloading of sensory information and the stress level has been proven to be higher due to constant accessibility. Furthermore, the new distance can cause companies to lose their employees' attachment [17]. Still, digitalisation in Germany, especially for small and medium-sized enterprises (SMEs) in rural areas, can provide more opportunities worldwide with the availability of skilled workers and improved work-life balance [17]. The goal of the agileKMU project is to develop a digital platform for agile collaboration to design (smart) production systems as shown in Fig. 2. The platform supports the agile collaboration with a goal-oriented provisioning of planning data, a custom workflow management system, and flexible visualisation concepts.

It is assumed that the integration of the digital platform will improve collaboration for SMEs, especially in the design of production systems. Refining the tasks for the Kanban board carries the most significant challenge and benefit at the same time. Adequate effort estimations and task refinements represent initial barriers. The increased transparency of processes in the project significantly simplifies communication between employees. In addition, the task-related data connection streamlines collaboration with other departments. This enables project staff to increase the proportion of their core tasks and reduce the proportion of their secondary tasks (e.g. administrative and organisational processes). Research concepts include collaborative work in VR to enrich collaboration with additional information or connect distributed teams.

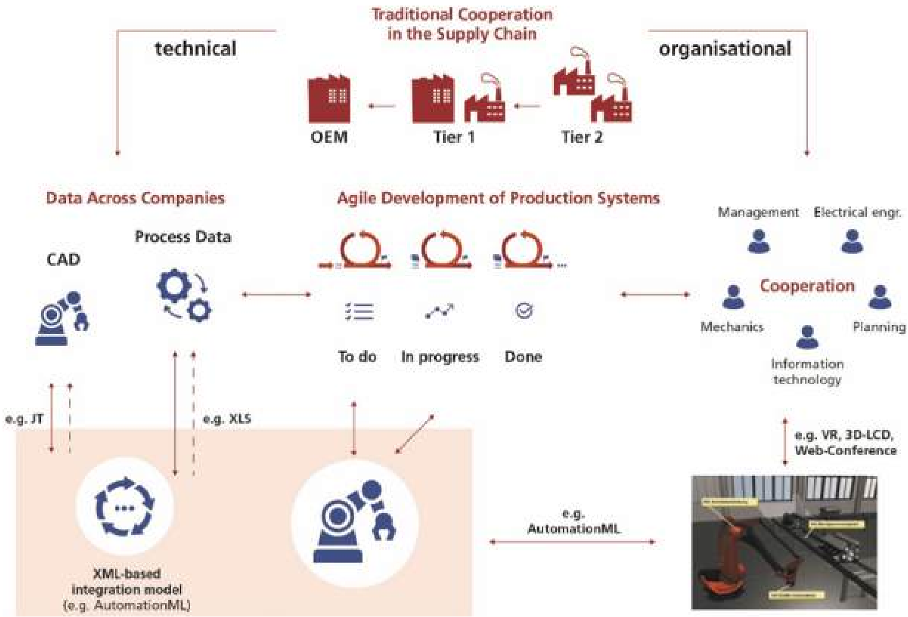

Fig. 2. Digital platform to facilitate distributed collaboration in the agile design of smart production systems, own illustration based on [19]

2.2 The Change of Planning Processes for and with New Technologies

VR can support agile work in interdisciplinary teams, facilitating not only members working together from multiple locations. With the help of suitable software and hardware, VR can create a controllable experience, expanding collaboration and information dissemination beyond web and video conferencing.

The transformation of cardboard engineering, together with VR-supported collaboration, lays the foundation for the expansion of interactive methods in work system design in order to meet shortened product life cycles and customer requirements. VR technology has been increasingly utilised in planning smart production systems to visualise workstations or construct them with digital cardboard engineering [20, 21].

However, it should be noted that the requirements for effective collaboration and functional distribution of roles in virtual cardboard engineering show a high degree of complexity compared to physical interaction [21]. Working as a team in this virtual space is referred to as Collaborative Virtual Environment (CVE). Not only do CVEs allow spatially separated people to interact, but they also enable the interaction between those people and virtually simulated objects [22]. CVEs represent a framework for successful virtual collaboration, which must be detailed for the concrete consideration of virtual cardboard engineering with the help of defined scenarios. In classical cardboard engineering, direct, face-to-face communication is supported by whole-body movements, gestures, and joint interaction on a prototype, enabling the formation of a shared understanding of the subject of discussion. VR offers the possibility to partially realise this vital support of communication by implementing a realistic avatar [22]. Another influencing factor on collaboration is, among others, the simultaneous use of different media. Besides the possibility of all participants viewing the virtual environment through VR headsets, screen projections can visualise the process for non-VR users. As a result, possible scenarios of VR applications emerge.

There are four different workshop scenarios while using VR applications as a collaborative tool, each presenting a specific impact based on the focus of the task. In scenarios one and two, all participants are equipped with VR headsets; while participants in scenario one work together in one physical space, scenario two separates them into groups and allows them to work remotely. Participants in scenarios three and four are divided into VR users and non-VR users, while the non-VR users can only view the work system through transfer screening. The difference lies, again, in the physical space in which the workshop takes place [23]. The defined scenarios support interactive collaboration in VR so that the same results and discussion content can be achieved compared to a physical meeting of an interdisciplinary working group. However, it must be noted that the use of VR, other than being a collaborative tool, also impacts tasks and authorisations, which can be recorded with a role construction.

The participants' roles are defined through task- and authorisation-oriented concepts. Task-oriented roles allow VR and non-VR users to take up different charges of the cardboard engineering workshop. On the other hand, authorisation-oriented roles restrict the functionality of VR applications for each user distinctively. Therefore, to ensure an efficient VR working experience for smart production systems and the future of new product integration, workshop requirements should be collected and included in a development process before conducting virtual cardboard engineering [23]. For example, motion-economic evaluations of the process based on the virtual execution of the work method require new competences with respect to the rule-compliant application of conventional evaluation methods and the transfer performance to a real process.

The interaction between role concepts and facets of collaboration can significantly impact media-supported interaction. In addition to using developed scenarios one of the most crucial factors to ensure the future success of cardboard engineering in the digital and virtual world is an extensive and consistent data basis as discussed at the beginning of the chapter.

2.3 The Emerging Role of Data Science and IoT in Engineering Smart Production Systems

The handling of data in its different forms and usages is one of the main challenges in Industry 4.0 concerning all technologies. The value-adding use of constantly increasing and available amounts of data is becoming a decisive competitive factor and is the basis for intelligent products, processes, and production technology. In mechanical and plant engineering and especially in the design of smart production systems, new roles and requirements emerge. Machine Learning (ML) as the basis of AI poses great challenges for companies, as the demand for experts, so-called Data Scientists, significantly exceeds the offer of available young talents. Furthermore, these experts rarely have the required domain knowledge – the core competences of manufacturing companies. In this context, the new job description of the Citizen Data Scientist as a link between the most important disciplines of information technology, domain knowledge, and data science arises. The shift to increasing software-heavy and data-analytics-driven production system design affects large companies, which often have access to talent pools and resources to build up expert departments, but also small and medium-sized enterprises, whose digital sovereignty is progressively threatened. The ML2KMU project is therefore developing an interdisciplinary role model for the implementation of ML initiatives in the manufacturing industry with a special focus on SME and mechanical and plant engineering as the core of production system design [24]. Building on an assessment of the basic competences required for the individual roles, the focus is on in-service competence development. For this purpose, a platform is being developed from which individual development measures for individual employees in project teams can be derived in a targeted manner. In addition to the methodological changes presented above, especially professional qualifications place new demands on future work. In addition to ML skills such as mastering statistics, data integration and pre-processing, training and evaluation of machine learning methods as well as deployment and maintenance of models (especially when smart production systems with data-based services are handed over to customers), the focus is increasingly on IoT skills. This requires employees who, in addition to the classic programming of shop floor IT such as NC, robot or PLC programming up to the integration of the SCADA and MES level, also have the skills to transfer smart production systems into IoT platforms. All in all, three system worlds with the same perspective are emerging: classic document-based planning using digital planning tools with PDM and PLM backbones will continue to exist but must be able to react more flexibly and quickly to rescheduling and also take into account digital components of later production systems. The second system world of automation technology is also becoming more important as manual work in later production systems is increasingly replaced by automation technology. In addition, there are new requirements for the interoperability of the shop floor components themselves and, in particular, an opening of the automation pyramid to enable intelligent data use, e.g., by using protocols such as OPC UA or MQTT. The third perspective includes IoT competences, as smart production systems must be mapped on uniform structures and platforms in the sense of the digital twin in order to enable data-driven services. Examples are Siemens Mindsphere and PTC Thingworx, but hyperscalers such as Amazon or Microsoft (as well as numerous other solution providers) also offer corresponding modules. Overall, the effort and complexity of the planning phase are significantly increased, but at the same time, new opportunities for intelligent data use arise in the operating phase of smart production systems.

3 Operating Smart Production Systems

New technologies open up the possibilities to manage the rising complexity in production systems and improve work for employees. As presented in the following, some technologies such as data usage are the same as in the planning phase although partly used with another focus. Other technologies such as robots, exoskeletons or assistant systems are linked more directly to operating production systems.

3.1 Connectivity and Internet of Things in Operating Smart Production Systems

The technological foundations for the development of smart production systems were created by the exponential increase in the performance of the available hardware in terms of memory, computing, and transmission capacity, described by Moore's Law, with simultaneous miniaturisation of the hardware and falling prices. Supported by the flexibility of programmable software, this has led to the convergence of previously separate developments in the field of global digital networking and embedded systems based on programmable controllers, single-board PCs, and system-on-a-chip (SoC) [25, 26]. Already today, the far-reaching possibilities of global digital networks are combined with the potential of embedded software-based systems within modern production systems, creating the basis for mapping, monitoring, and controlling physical processes [26]. Embedded systems not only enable plants and components to communicate in an increasingly detailed and fast manner, but also products become capable of communication. In addition, cloud computing enables a scalable provision of computing and storage capacities in addition to comprehensive, platform-based networking of objects. This makes it possible, for example, to carry out computationally intensive analysis processes in the evaluation of large volumes of data that would not be feasible on the basis of embedded systems or internal company IT structures, or to provide data and services on demand [27]. The focus is on the Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), and Software-as-a-Service (SaaS) operating and business models. With IaaS, only the basic resources such as network, storage space, and computing power are provided. The user has control over the operating system and the applications. PaaS starts one level higher and, in addition to the components mentioned under IaaS, provides middleware that, for example, balances the distribution of the load. This form is aimed at developers who need a platform to publish applications (e.g. ML-based services) without having to maintain the operating system. SaaS, as the closest view to the user, enables solution providers to provide services to end users without having to provide the technical infrastructure and without bearing the responsibility for installation and updates. In sum, smart production systems are emerging that can be understood as the further development of mechatronic systems. The underlying disciplines of mechanics, electronics, and computer science, therefore, play an increasingly important role not only in planning, but also in operating, maintaining, and improving smart production systems [28]. The physical design on the one hand and, on the other hand, the digital representations of production systems mapped using IoT platforms in Iaas, PaaS, and SaaS structures must be continuously maintained and serviced. In addition to planning, new competences are required, extending from classic automation and programming to IoT platforms, network and communication technology, and data science. Competence requirements for the use of digital twins are also emerging on the user side. This could be, for example, the configuration of individual dashboards, but also the configuration of services and the derivation of actions from digital recommendations.

3.2 Flexible Production Systems

One of the new possibilities of operating smart production systems is the demand-oriented and flexible provision of resources for production orders, summarised in concepts like Factory-as-a-Service (FaaS). To address smaller and more flexible batch sizes in emerging competition fields, smart factories strive to unite flexible manufacturing with high transparency of production processes and thus bring about new demands on communication between all actors at field, customer, and supplier level. The efficiency of this interaction is a key success factor for globally positioned production networks. Production markets increasingly require internet-based business platforms to compare capabilities of smart factories with customer specifications, creating a market not only for products but also for production processes. In this environment, modular production systems will be particularly successful, as they can easily adapt to a broad product portfolio and different production volumes. The research project PHASE shows possibilities to build such a platform, which is based on permanently up-to-date digital twins of the production systems and especially the capabilities and configurations of the respective components (Fig. 3). Building on the same foundations, the CSC research project focuses on the technical documentation of flexible, changeable production systems over the life cycle, which is both a planning and a maintenance task [29]. This is another example of new services that are only made possible by digitisation, since manual maintenance (as well as the reconciliation of production capacities in the previous example) quickly reaches its limits of flexibility and economic efficiency. With regard to the change in work, it can also be seen here that new digital competences are required in the creation, usage, and maintenance of digital twins and services in the context of smart production systems. On the other hand, they enable new options that were not possible with formerly physical manual work.

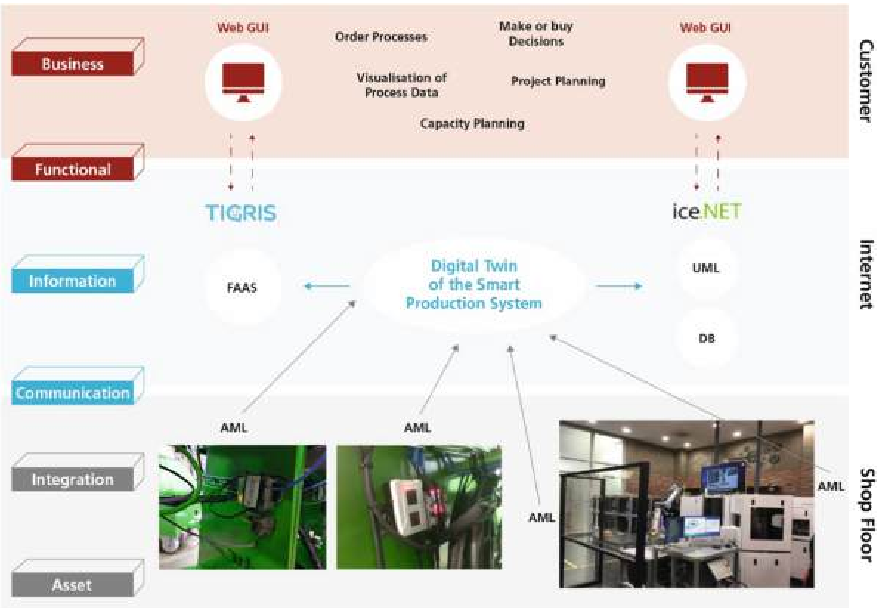

Fig. 3. Flexible Hybrid FaaS concept within the research project PHASE (own illustration).

An example of production systems that provide such flexibility is the usage of cobots, small, light and affordable robots, which no longer need to be caged for safety reasons but can interact and collaborate with humans. The research project SUPPLY focuses on integrating cobots into flexible manpower lines. Depending on the required quantity, one or more cobots can be integrated into the assembly increasing the output without requiring additional staff. Especially short-term increases in demand can be covered more easily. To realise this potential, the products need to be designed to be handled by humans as well as cobots. Not all steps in assembly can be automated today, therefore humans remain an essential part of assembly systems. But increasing the steps cobots can be used for, especially repetitive or non-ergonomic ones increases the flexibility of production systems while relieving humans. However, the successful implementation of those systems requires technological advances as well as new qualifications. Beginning with the product design, designers need to take into consideration the capabilities of cobots, e.g. designing suitable grip surfaces as well as reducing flexible components [30]. Also, assembly system planners need to be qualified to integrate this new technology effectively into production systems. User-friendly simulation software, such as has been used in the research project KoMPI can enable non-robotic experts to plan and verify different scenarios. Simulation can also help to reduce the effort and time needed to teach the different scenarios to the physical cobot. Further development is to directly create robotic programs from simulation [31]. However, the specific language of every robot manufacturer poses a challenge. Another possibility to teach robots and especially cobots more easily is learning by demonstration [32]. The possibilities to teach robots by guiding them manually or using a trace pen are already implemented [33]. To directly capture the human movement in the production process and transfer it to the cobots is still a research focus [34]. The integration of cobots also changes the work on the shop floor. Human workers are working side by side without a separating fence. Whereas before, problems with an industrial robot could only be handled by robotic experts, now small problems will need to be handled by line workers to avoid standstill. More user-friendly control panels are facilitating this new task for line workers. Whereas teaching the robots today is handled by experts, the new teaching approaches open up the possibility to transfer this task to line workers while simultaneously reducing set-up times.

3.3 Worker Assistance Systems

However, not all non-ergonomic tasks in flexible production systems can be easily automated by using cobots. In such cases like e. g. non-stationary activities exoskeletons present a novel solution [35]. Exoskeletons are defined as wearable mechanical structures that relieve the musculoskeletal system during certain movements or postures [36]. Depending on the mode of operation, active and passive systems can be differentiated. Active exoskeletons have an energy source that supports or amplifies human movements. Passive systems on the other hand do not feature an external energy supply but use passive possibilities like springs to store and release energy [37].

An alternative classification of exoskeletons is based on the supported body regions. The most common systems on the market are trunk- and shoulder-arm support systems while full-body solutions are hardly commercially available [38]. Whereas exoskeletons have been widely investigated for applications in the military or healthcare, their usage in production environments has only recently gained increasing intention with the release of several specific systems for industrial use cases [39]. Due to this novelty, there are still a number of open questions concerning the application of exoskeletons. The research project SyNExo, therefore, addresses the systematic introduction of such systems in production and logistics. Initial results of an explorative interview study indicate that besides the associated costs, the technology acceptance of operators is currently an important adoption barrier. For example, exoskeletons may be rejected due to movement restrictions in secondary activities like walking or sitting at a computer desk [40]. Thus, in addition to investigating the long-term effects of exoskeletons further research is required on the multi-faceted construct of technology acceptance to fully unravel their potential to prevent musculoskeletal complaints.

While cobots and exoskeletons provide support regarding physical stress, operators in future smart production systems are also faced with highly dynamic environments leading to mental stress. The increasing number and fast change of product variants increase system complexity and cognitive demands for operators [41]. For that reason, it is not only necessary to consider physical loads but also to examine cognitive loads in the design of manufacturing processes [42]. Therefore, it is necessary to distinguish between two types of operator assistance systems, which are highlighted in Table 1 [43]. Energetic assistance systems like cobots or exoskeletons serve to reduce the physical stress on human workers by providing physical support when e.g. lifting loads. In contrast to this, the purpose of informational assistance systems is to lower mental stress by presenting necessary information according to the operators' needs. Exemplary technological applications for this category are AR glasses, tablets or projection-based systems.

Table 1. Classification of operator assistance systems based on Bornewasser and Hinrichsen [43]

	Energetic assistance systems	Informational assistance system
Purpose	Reduction of physical stress	Reduction of mental stress
Function	Provision of physical support	Provision of necessary information
Examples	Cobots, exoskeletons	AR glasses, tablets

One promising use case for informational assistance systems is operator training. Especially in manual assembly, product variety leads to more complex tasks, as many different assembly procedures have to be managed by operators [44]. Conventional training methods like demonstrations or paper-based instructions are not sufficient to ensure the necessary flexibility of workers [45, 46]. Informational assistance systems provide novel opportunities for technology-mediated learning by providing timely and context-specific information on assembly processes. Potential benefits of this approach have already been demonstrated in several studies. Assistance systems can reduce execution times especially at the beginning of training and help to maintain a higher process quality by preventing errors [47, 48]. Despite these promising results, the lack of knowledge about the wide range of available technologies as well as related high-potential use cases remain open issues. In order to promote the dissemination of assistance systems in industrial practice, methods for a structured selection of application scenarios and the user-centred implementation need to be developed [49]. The latter also includes suitable approaches for integrating product variants by linking them to the corresponding IT infrastructure [50].

4 Improving Smart Production Systems

As the past has shown, simply planning and then operating a production system does not lead to success. Especially the dissemination of lean management has stressed the importance of continuous improvement as a success factor [51]. The following sections show, how Industry 4.0 can support continuous improvement.

4.1 From Classic Improvement Methods and Roles to Digital Shop Floor Management

Methods from the field of lean management are increasingly merging with developments in Industry 4.0, as new possibilities for data collection and evaluation are emerging. The GaProSys 4.0 project, for example, addresses the development of a selection system for methods of a “Holistic Production System 4.0” for SMEs [52]. In the following, new possibilities in the widespread methods of shop floor management, bottleneck analysis, value stream analysis, and design are presented.

Classic shop floor management (SFM) addresses the economic operation of production systems and value streams as well as systematic continuous improvements by employees. The goals are to create an organisational framework that empowers employees to engage in continuous improvement processes (CIP) to improve and stabilise processes in manufacturing [53]. The core elements are on-site communication and leadership, transparency through visual management, and the promotion of a structured problem-solving process. While these tasks are conventionally carried out through shop floor management boards, which include (often manual) records of unit numbers and key figures of quality or productivity, they are not always carried out on the shop floor. Due to the increasing opening of shop floor IT up to the implementation of Industrial IoT platforms and digital twins, shop floor management can be supported digitally.

The advantages are time savings and error avoidance in data collection through connection to ERP/MES systems, possible use as a communication and information tool across departmental boundaries, and automation of write-ups. However, the challenges lie firstly in the development and maintenance of such a digital tool, and especially in its application. For the employees, this results in new requirements to set up, maintain and evaluate dashboards. However, if these competences are given, new possibilities arise for the flexible configuration of interesting visualisation forms for specific problems, e.g. for data-based error and error cause analysis.

On a system level above specific problem-solving in individual processes, value stream analysis (VSA) and value stream design (VSD) are widespread methods for visualising and modelling material and information flows and are used to analyse existing and design future value streams [54]. They help to map and improve material and information flows as well as value creation processes in a transparent and simple way.

In the conventional form, in which value streams are mapped with pen and paper, they represent a snapshot of the current state. However, the method reaches its limits, especially in the case of a high number of variants and flexible process routes up to shared resources, as they occur in the development of CPS. Dynamic value stream analysis (DVSA), which enables a time-dynamic view, can help. An overview of the general methodological approaches of the DVSA and their implementation to date can be found at reference [55]. The DVSA makes it possible to monitor different product routes, cycle times, the real behaviour of inventories and lead times, and to analyse static dynamic and dynamic bottlenecks. It is often implemented at the MES level, but another trend also moves towards IoT platforms and the implementation of data-driven services. Figure 4 shows the implementation of DVSA services, including dynamic bottleneck analysis by IPSO Factory.

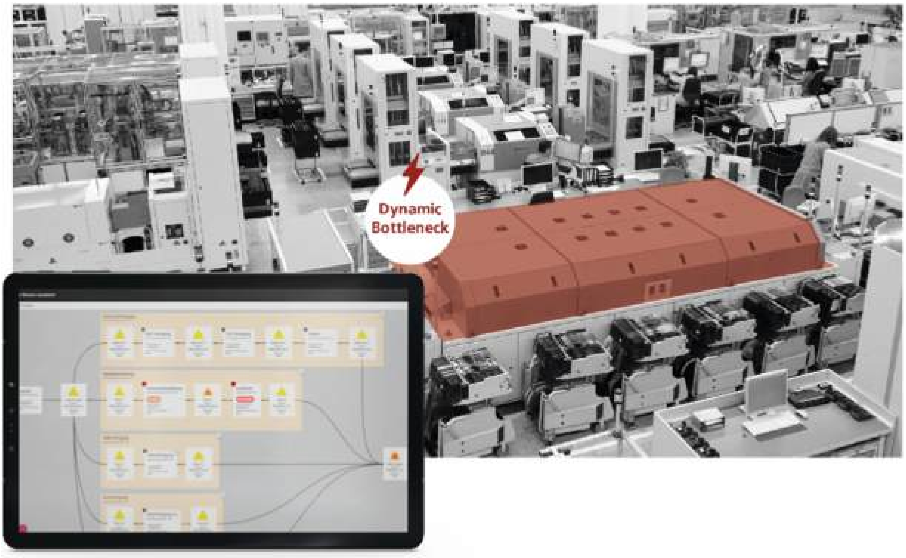

Fig. 4. Dynamic value stream and bottleneck analysis (IPSO Factory)

For the employees, however, this also poses the challenge of commissioning and permanently operating the platforms and additional IT systems. This results in new digital competence requirements. On the one hand, new roles are emerging for the maintenance of productive shop floor IT systems. On the other hand, process experts are required to be able to operate and configure the systems. Production staff must also be qualified to use the systems, not only to interpret visualisations on the dashboard but also to create them in a customised way.

4.2 Industrial Data Science Changes the Possibilities and Requirements of Improvement Processes

Conventional CIP processes are based on the application of lean methods, e.g. the identification and elimination of waste. In quality management (QM), however, the requirements are more stringent, as it must be ensured that only good parts are delivered to customers. Therefore, data-driven approaches are already in use in this domain, especially those that address the identification of errors and error causes. The design of inspection and rejection strategies and the application of statistical methods from the field of Six Sigma have already led to production in the ppm range (parts per million) in many factories. On the one hand, the successes are based on very high inspection volumes and the rejection and reworking of defective parts; on the other hand, conventional statistical methods such as correlation analyses reach their limits with multivariate and often cross-departmental data sets. In particular, in quality management, the methodological toolkit of the product and process improvement team is therefore extended to include the application of machine learning (ML) as part of AI. The most common applications in QM are advanced fault diagnosis and root cause analysis based on large amounts of data as well as the prediction of quality metrics based on product and process parameters in order to reduce the load on inspection gates or to be able to proactively interact in process control. One example is the "QU4LITY" project. The goal of the EU project is the realisation of application-oriented and data-driven Zero Defect Manufacturing (ZDM). An essential aspect of the project is the reduction of defect costs of automatic process control in the production of electronic components by reliably anticipating the resulting product quality already during the production process. Based on the anticipated product quality, corrective actions are to be derived for the subsequent production process, so that the test efficiency is increased in the entire value stream. The latter objective requires the development and integration of virtual sensors into the production processes to ensure detailed and digital documentation.

In general, this results in new heterogeneous competence requirements for the workforce. Cooperation between domain experts, management, IT, and data science has established itself as a success factor for data science projects. The main challenge is that the corresponding competences must either be acquired externally or built up internally. The ML2KMU research project presents a role model in which competence profiles are defined. Furthermore, the AKKORD project offers a platform for identifying on-the-job data science training courses [56]. In addition to the development of technical framework conditions such as IT architectures and IoT or data science platforms, the development of new digital competences and the orchestration of specialist teams are of great importance in order to be able to realise the potential of digitalisation.

5 Conclusion and Outlook

As described above, Industry 4.0 is changing work in all areas of production, from production planning to operation and improving smart production systems. In production planning new consistent software tools as well as VR open possibilities for faster and more accurate planning e.g. using simulation and VR to test new systems intensively and improving them, before buying a physical system. New technology also allows working in interdisciplinary teams from different locations reducing travel time and cost as well as making experts better available. Nevertheless, to realise this potential, new ways to organise the work in an agile way are required. Employees need new skills to work with new technology but also need to learn to organise work differently. To address these changes new job descriptions arise. However, professional training and study programmes are only slowly changing, not yet able to meet the demand for experts. As described one of the most prominent examples are Data Scientists. Adequately using huge amounts of data and realizing the potential of Industry 4.0 is one of the most fundamental challenges. Competences in connection to working with data are often summarised as Data Literacy. Data Literacy not only includes knowledge needed by Data Scientists, but today a certain data understanding is required in all areas and career paths [57]. Equally, new competences are necessary concerning IoT, commissioning or operating platforms and networks.

However, not only work and competences in planning functions and jobs with higher education are changing but also working on the shop floor requires new skills. As described e.g. working alongside or even in collaboration with robots requires some basic knowledge of automation. On the one hand, new connectivity, smart machines, and higher automation facilitate work, on the other hand, new sources of error arise that need to be recognised and corrected. Additionally, the required flexibility and short reaction times are challenging. Informational assistance systems can help to manage this situation, but also require training the workforce in the correct usage. Due to the speed of the change in Industry 4.0 continuously and lifelong learning gains increasing importance. Knowledge acquired in formal education will be outdated within a few years forcing companies to new and continuous ways of learning.

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Scenario-Based Foresight in the Age of Digital Technologies and AI

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Abstract. Scenario-based foresight is used less and less in the corporate world despite continued high satisfaction with the obtained results. In the age of digitalization, many companies feel increasingly forced to short-termism instead of strategic planning. However, emerging digital technologies, such as artificial intelligence (AI), represent a promising approach to cope with the traditional challenges of scenario-based foresight as well as new challenges added by digitalization. Therefore, this work-in-progress paper identifies and analyzes use cases for scenario-based foresight with digital technologies employing a systematic analysis of the relevant literature.

In the paper at hand, we show that the use of digital technologies for improving the performance of scenario-based foresight is an emerging field. We identify 14 so-called use cases, i.e., unique goal-oriented applications of digital technologies for scenario-based foresight. In general, the use cases show that currently digital technologies can enhance, not substitute the capabilities of scenario-based foresight practitioners. Digital technologies primarily support the analysis of large amounts of data, e.g., for collecting futuristic data and identifying key influence factors. However, activities that require implicit knowledge and creativity, like the interpretation of scenarios, are currently still left to humans.

Keywords: Scenario-based foresight · Scenario planning · Scenario technique · Digital technologies · Artificial intelligence · Explainability

1 Introduction

In the age of digital technologies and artificial intelligence (AI), scenario-thinking, i.e., scenario-based strategic thinking and decision making, is on the verge of radical change. However, digital technologies and AI will not change the main principles of scenario thinking (Schühly et al. 2020): 1) Networked thinking, i.e., the consideration of the interconnectedness of influence factors, and 2) multiple futures, i.e., it is not possible to predict the future and therefore different development paths must be considered (Berger et al. 2008; Gausemeier et al. 2018). So, it is not the principles of scenario thinking that are changing. Rather, digital technologies and AI can change the way scenarios are developed and perceived (Schühly et al. 2020).

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Global megatrends cause a rapid and profound change in our world (Hamidian and Kraijo 2013). As a result, volatility, uncertainty, complexity, and ambiguity are increasing significantly in our environment. In this so-called VUCA (volatility, uncertainty, complexity, ambiguity) world, it gets more and more challenging to make valid long-term recommendations and statements with conventional scenario-based foresight (Schühly et al. 2020). With increasing availability of data and emerging powerful digital technologies, digitalization offers promising opportunities to deal with the ever-faster changes in the environment. However, digitalization also creates entirely new challenges for scenario-based foresight practitioners. These new challenges can be structured with help of the 5 Vs of Big Data: volume, velocity, variety, veracity, and value (Sagiroglu and Sinanc 2013; Demchenko et al. 2013):

- **Volume:** The amount of data is increasing exponentially. 2.5 quintillion bytes of data are created every day. This number will increase even further and faster than before in the coming years (Marr 2018). In addition to the amount of data, the number of relevant data sources is also increasing. Consequently, more data must be processed and analyzed in the same amount of time. If done right, this enables scenario-based foresight practitioners to make more informed data-driven decisions.
- **Velocity:** Velocity measures how quickly data are coming in. Whereas some data come in batches, other data come in in real-time. Therefore, the different velocities present a challenge for analysis. On top, with increasing volume and velocity, the half-life of information decreases. For scenario-based foresight, that means that scenarios must be monitored and revised more frequently.
- **Variety:** Data can be structured, semi-structured or unstructured. For the use in scenario-based foresight, a pre-processing of the data is required.
- **Veracity:** Veracity means that data need to be consistent and trustworthy. Consequently, scenario-based foresight practitioners also need to carefully assess the quality of futuristic data.
- **Value:** The value of data is measured by the value contribution that collected data can bring for a specific goal. For scenario-based foresight practitioners, it will become a crucial task to distinguish relevant data sources from less relevant ones, e.g., in the identification of key influence factors.

These challenges induced by the information age only add to the already existing, traditional challenges of scenario-based foresight. Traditional challenges include, in particular, the high complexity of the methodology itself and the large amount of time required for its application. Consequently, the use of scenario-based foresight is declining in practice, although satisfaction with the obtained results remains at a high level (Rigby and Bilodeau 2018; Bain and Company 2018). In the VUCA world, companies rather tend to focus on short-termism than on long-term planning (Barton et al. 2018). Studies have shown, however, that companies who systematically make use of (scenario-based) strategic foresight are significantly more successful and less volatile in the long term than their short-term oriented competitors (Barton et al. 2018; Rohrbeck and Kum 2018; Rohrbeck et al. 2018). In order to enable companies again to use scenario-based foresight more, it is necessary to find a way to improve its overall performance and adapt it to the surrounding circumstances in the age of digitalization.

In scenario-based foresight, we can distinguish between two major directions of thrust: scenario planning and scenario technique. Scenario planning is a deductive methodological approach. A typically predefined number of scenarios is developed with the help of a rigid scenario framework. In contrast, scenario technique is an inductive methodological approach. Future scenarios are developed by systematically combining consistent alternative development paths of key influence factors, so-called future projections (Götze 1993; Fink and Siebe 2011). Although the two major directions of thrust differ slightly in specific steps, the general steps, activities, and stages are closely related to each other. Subsequently, we will not differentiate between the two directions of thrust. Rather, we will refer to the overarching and summarizing concept of scenario-based foresight. Its evolution over time is shown in Fig. 1.

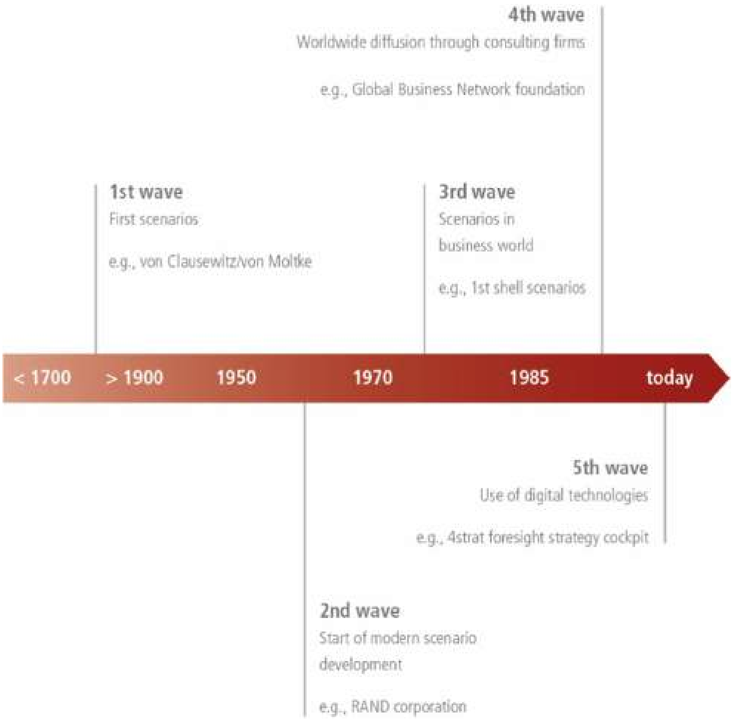

Fig. 1. Timeline of scenario-based foresight (own illustration based on Schühly et al. 2020)

In the context of strategic planning, scenarios were used for the first time by the military (first wave). The start of modern scenario development began right after World War II, when the US military worked together with the RAND corporation on future scenarios (second wave). Later, the company Royal Dutch Shell brought scenarios into the corporate world. With scenario-based foresight, the company was better prepared than most of its competitors for the oil price shocks in the 1970s (third wave). In the mid-1980s, the use of scenario-based foresight by multiple consulting firms like the Global Business Network led to its worldwide diffusion (fourth wave). Today, the fifth wave of scenario-based foresight is emerging. Emerging digital technologies, like AI, can and will change the way how scenarios are created and perceived (Schühly et al. 2020).

According to Lipsmeier et al. (2018) "digital technologies [...] comprise knowledge, skills and know-how for the creation, processing, transmission, and use of digital data as well as systems and procedures for practical implementation" (p. 32). Following the work of Berger et al. (2018), we can differentiate infrastructural digital technologies, application-oriented digital technologies, and service-oriented digital technologies. Infrastructural digital technologies, like platforms and connectivity technologies, as well as application-oriented digital technologies, like sensors and actors, can be considered prerequisites and enablers for further digital technologies. The so-called service-oriented digital technologies have the potential to enhance the performance of scenario-based foresight, e.g., by increasing the efficiency of the methodology or by increasing the quality of results. Service-oriented digital technologies cover the range of technologies for analytical insight generation (e.g., machine learning), analytical interaction (e.g., virtual assistant), and augmented interaction (e.g., gesture control) (Berger et al. 2018). Service-oriented digital technologies possess the ability to collect vast amounts of data, analyze data, extract knowledge from data, and even support decisions (Porter and Heppelmann 2014; Belger et al. 2019; Acatech 2020). Therefore, it can be concluded, that digital technologies may provide a technology-based answer to the new technology-induced challenges and the traditional challenges of scenario-based foresight (Schühly et al. 2020).

In practice, there are already first applications, which make use of digital technologies, e.g., AI techniques, in order to improve the performance of scenario-based foresight. One example is the foresight strategy cockpit of the company 4strat. The application supports different foresight activities, e.g., scenario building and (semi-)automatic trend monitoring (4strat 2022).

To systematically identify use cases of digital technologies for scenario-based foresight, existing approaches from the literature should be analyzed. Therefore, this work-in-progress paper aims to answer the question: *Which use cases for digital technologies exist in the literature, that can improve the performance of scenario-based foresight?* We conducted a systematic literature analysis to create a first overview of the existing use cases.

2 Research Design

Our research design for the systematic literature analysis is based on the guidelines of Webster and Watson (2002) (see Fig. 2). The review is structured in four sequential phases: 1) definition of search strategy; 2) definition of search string; 3) conduction of search; 4) analysis and evaluation of approaches. Subsequently, all phases and their results are described in more detail.

1) Definition of Search Strategy

A search strategy includes the research question for the systematic literature analysis, information on the time frame to be analyzed and the language of the publications to be analyzed, as well as the relevant databases to be searched (see Fig. 3). The research question has already been derived in Sect. 1. The time frame for the search for relevant

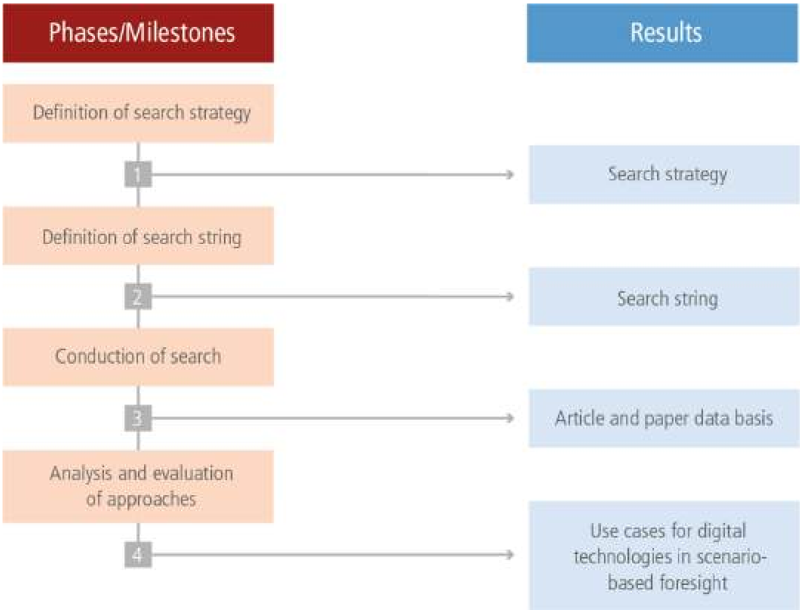

Fig. 2. Research design for literature review (own illustration based on Webster and Watson 2002)

sources is deliberately not narrowed down in order to also identify early approaches for scenario-based foresight that already make use of digital technologies. Furthermore, the databases are searched exclusively for English scientific publications because English is commonly used in the relevant literature in the field of scenario-based foresight.

For the selection of the relevant databases, five renowned databases for scientific publications were reviewed for suitability: Scopus, IEEE, Web of Science, ScienceDirect, and Wiley. For this purpose, the two directions of thrust for scenario-based foresight were used as search terms: “scenario planning” and “scenario technique”. The databases ScienceDirect and Web of Science were selected because they contained the highest numbers of relevant journals and conferences in the context of scenario-based foresight. Other relevant journals and conferences from the non-selected databases and the experiential knowledge of the authors in the context of scenario-based foresight were collected in a list for an additional manual search. This list included, e.g., the International Journal of Foresight and Innovation Policy. After determining the search strategy, the search string is defined.

Language	Time frame	Databases
English	Not limited	ScienceDirect, Web of Science

Fig. 3. Search strategy components (own illustration)

2) Definition of Search String

The search string was defined iteratively (Marcos-Pablos and García-Peñalvo 2018). The initial search string was revised and finalized in three iterations, each with different researchers as sparring partners. General structuring frameworks for digital technologies and AI, such as Papers with Code (2022), and foresight-specific structuring frameworks, such as van Belkom (2020), were considered as input for the initial definition and iterative refinement of the search string. The final search string is thereby composed of two elements S1 and S2. S1 includes the two directions of thrust for scenario-based foresight and eight synonyms that are commonly used in the literature. S2 comprises 18 search terms derived from the considered structuring frameworks for digital technologies and AI. Figure 4 shows the search string.

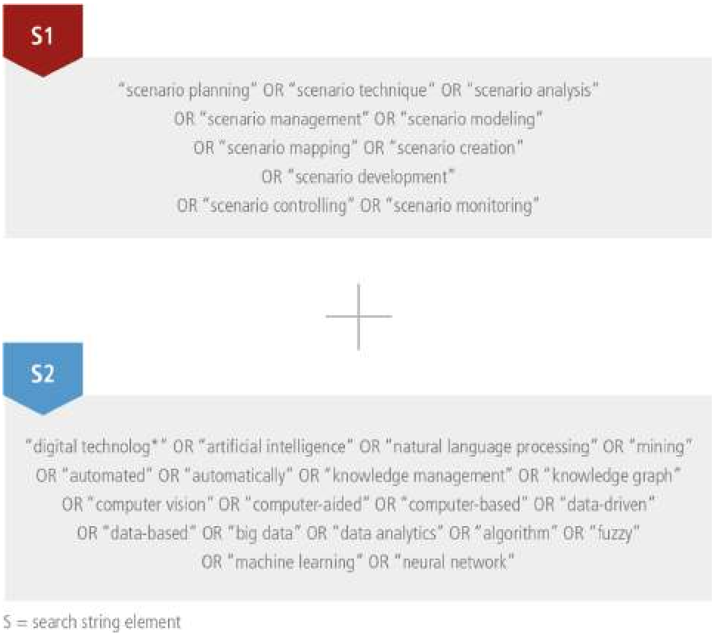

Fig. 4. Search string

3) Conduction of Search

The actual conduction of the search itself takes place in phase 3. The steps of the search are shown in detail in Fig. 5.

Fig. 5. Selection process of papers and articles (own illustration based on Webster and Watson 2002; Xiao and Watson 2019)

First, the databases ScienceDirect and Web of Science were searched using the developed search string. As a result, 1802 potentially relevant scientific publications, i.e., journal articles or conference papers, were identified. Second, these publications were checked for relevance based on their title. All clearly non-relevant publications were removed. In addition, duplicates were removed as well. 208 potentially relevant scientific publications remained. Third, the publications were checked for relevance based on their abstracts. This reduced the number of potentially relevant sources to 103. Fourth, the publications were checked for relevance based on the full texts. In this way, a total of 18 relevant scientific publications were identified that contain at least one approach to scenario-based foresight with digital technologies. The final database also contains eight additional publications that resulted from the manual supplementary search. The database thus comprises 26 scientific publications.

After the formation of the publication database, we analyze and evaluate the papers and articles in detail (phase 4). First, we investigate the papers regarding their publication dates to get a refined view on the development of the topic over time. Then, more general use cases for digital technologies for scenario-based foresight are extracted from the papers. Last, the resulting use cases are analyzed in more detail, e.g., regarding their degree of explainability. The results are shown in the next chapter.

3 Results

Overall, a slight increase in the publication rate can be observed from the year 2016 onwards compared to the years before. This supports the thesis that we are currently just at the beginning of the 5th wave of scenario-based foresight, the *scenario-based* *foresight with digital technologies* (c.f. Sect. 1). Figure 6 shows the distribution of the selected 26 publications over time.

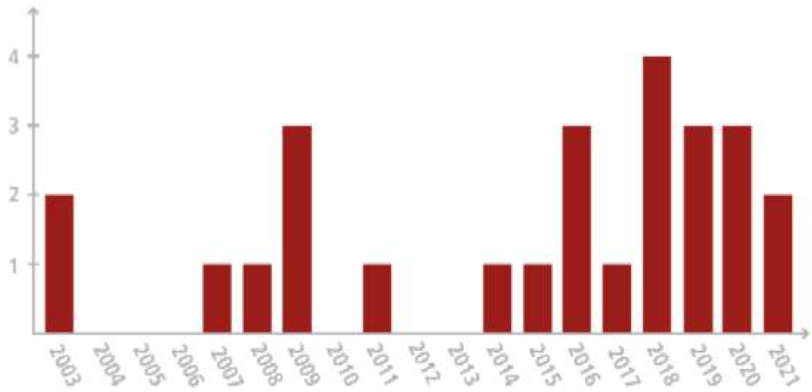

Fig. 6. Analysis of publications year-by-year (own illustration)

To analyze the 26 scientific publications of our database regarding possible use cases, we first define a use case for scenario-based foresight with digital technologies as *the goal-oriented application of one or more digital technologies, e.g., a specific AI technique, for a stage, step, or activity of scenario-based foresight*.

Following this definition, a total of 38 mentioned use cases can be identified from the sources. However, as some authors published consecutive papers dealing with the evolution of the exact same approaches, there are some identical use cases in the long list. After removing the duplicates, 27 use cases remain. However, several of the 27 use cases support the same goal with different digital technologies, i.e., they support the same stage, step, or activity of scenario-based foresight. As a results, the 27 use cases can be clustered to 14 unique use cases.

For example, Kim et al. (2016); Kayser and Shala (2020); Şahin et al. (2003) all describe the identification of (key) influence factors with the help of digital technologies. The three possible use cases therefore all pursue the same goal, i.e., they can be clustered to one unique use case (see use case no. 2). However, all authors rely on different digital technologies for the identification of influence factors. While Kim et al. (2016) as well as Kayser and Shala (2020) propose topic modeling and concept mapping, two approaches from the field of text mining which is part of natural language processing, Şahin et al. (2003) rely on the use of an artificial neural network. Therefore, different digital technologies can be considered for the implementation of each use case. Moreover, a possible solution approach can be based on a combination of several digital technologies. This can be seen for example in use case no. 8 (generate scenarios). Feblowitz et al. (2021) propose a combination of a domain-independent top k-planner and a (simpler) hierarchical clustering algorithm with a soft time limit.

Figure 7 shows the list of the 14 identified use cases. In addition to the addressed stage, step, or activity of scenario-based foresight, the list also includes the 23 digital technologies that can be used to realize the use cases, as well as the associated sources.

Use Cases			
No.	**Scenario-based foresight (stage, step, or activity)**	**Digital technologies**	**Sources**
1	Collect futuristic data as input for identification of (key) influence factors	Web mining	Kayser and Shala 2020
2	Generate suggestions for (key) influence factors	• Rule-based algorithm • Topic modeling, e.g., latent • semantic algorithm (text mining) • Concept mapping (text mining) • Artificial neural network	Kim et al. 2016; Kayser and Shala 2020; Batrouni et al. 2018; Şahin et al. 2003; Feblowitz et al. 2021; Backhaus et al. 2018
3	Conduct influence analysis	• Fuzzy association rule mining • Fuzzy linguistic MICMAC	Kim et al. 2016; Villacorta et al. 2014
4	Select key influence factors	• Modified page rank algorithm • Concept of generalized area centrality	Gräßler et al. 2019; Backhaus et al. 2018
5	Identify relevant triggers and events for scenarios	Web crawler	Sharma and Young 2015
6	Semi-automatic filling of consistency matrix	• Use of pre-defined consistency patterns • Fuzzy rule-based system	Gräßler et al. 2020; Dönitz and Möhrle 2009
7	Decompose consistency matrix	Modified design structure matrix algorithm	Backhaus et al. 2018
8	Generate scenarios	• Adaptive Neuro-Fuzzy Inference System • Top k planner and hierarchical clustering algorithm	Moayer and Bahri 2009; Feblowitz et al. 2021
9	Determine and select scenarios	• Selection algorihms Inference System • Combination of hierarchical and non-hierarchical clustering using self-organizing map neural network	Tietje 2003; Şahin et al. 2003; Pishvae et al. 2008
10	Generate fuzzy cognitive model for scenario	Fuzzy cognitive mapping expert system	Nápoles et al. 2018
11	Conduct what-if-analyses for scenarios	Sensitivity analysis	Nápoles et al. 2018
12	Classify documents to support scenario writing	Dictionary algorithm	Fergnani and Jackson 2019
13	Identify, extract subjective perspectives in input documents for scenario writing	Sentiment analysis	Fergnani and Jackson 2019
14	(Continuous) supervision of key assumptions of scenarios	Feature selection algorithm	Batrouni et al. 2018

Fig. 7. List of 14 identified use cases (own illustration)

Use cases nos. 1 to 5 refer to the phase of identifying key influence factors.[1] Text mining approaches are particularly suitable for analyzing large amounts of data in order to generate suggestions for influence factors. This is in line with the findings and experiences of Bauer et al. (2022), Steinmüller (2022), and van Belkom (2020). Afterwards, humans need to discuss and add to the proposed key factors before selecting the key factors (Kayser and Shala 2020).

Further use cases show a similar pattern. Use cases nos. 6 and 7, e.g., primarily aim at reducing the evaluation effort in the context of determining scenarios. But the actual evaluation or the definition of necessary rules for rule-based approaches is still performed by humans (Dönitz and Möhrle 2009; Backhaus et al. 2018; Gräßler et al. 2020). With regard to divergence, a characteristic of socio-digital sovereignty (Hartmann 2020; Hartmann 2022), humans have extensive intervention capabilities throughout those use cases, and thus have autonomy and discretion regarding different courses of action.

Use cases nos. 12 and 13 refer to the elaboration of the scenarios. Digital technologies provide the input for this activity, e.g., by means of a classification of useful documents by a dictionary algorithm (Fergnani and Jackson 2019). The creative elaboration itself is ultimately carried out by humans.

Tasks such as defining the object of investigation, projection development or scenario interpretation, which require creativity, tacit knowledge, or qualitative data, are left to humans. In this context, digital technologies can specifically complement human capabilities, e.g., by taking over the analysis of large data sets (Bauer et al. 2022; Steinmüller 2022; van Belkom 2020).

Consequently, the scope of support provided by digital technologies is currently (still) limited. For clarity, we structure the use cases with the help of a stage model for the use of digital technologies. The stage model represents a synthesis of the knowledge ladder according to North (2016) and the four capabilities of smart, connected products (Porter and Heppelmann 2014). This results in four stages for the use of digital technologies: 1) collect data, 2) analyze data, 3) generate knowledge from data, 4) support decisions.

We must note that the stages do not allow any direct statements concerning the intelligence or explainability of the digital technologies described in the use cases. Furthermore, a single use case can be simultaneously assigned to different steps of the step model if the functional scopes of the proposed digital technologies for its realization differ significantly in their scope of support. Figure 8 shows the use cases assigned to the four stages of the stage model for the use of digital technologies.

[1] For the general stages of scenario-based foresight, cf. (Huss and Honton 1987; Götze 1990; Fink and Siebe 2011; Ködding and Dumitrescu 2022).

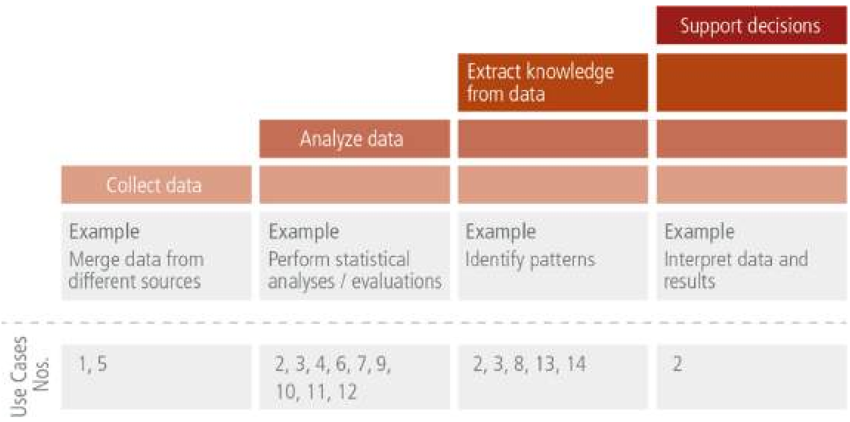

Fig. 8. Use cases classified according to the step model for the use of digital technologies (own illustration based on North 2016; Porter and Heppelmann 2014)

A glance at the chart confirms that digital technologies are currently most frequently used to analyze large volumes of data. While there are a few cases, where knowledge is generated from data, only one use case supports the user in decision-making. This is the identification, or rather recommended proposition of influence factors with the help of an artificial neural network (see use case no. 2).

However, the scope of support of the use cases does not allow any conclusions to be drawn about the explainability of the digital technologies used. For the concept of digital sovereignty, explainability of digital technologies is a crucial component (Hartmann 2020; Hartmann 2022). For this purpose, we have derived four categories for the analysis of the degree of explainability of digital technologies (see Fig. 9). The categories are based on the work of (Ilkou and Koutraki 2020; Lawson et al. 2021). It comprises four stages: 1) (procedural) algorithm, 2) symbolic AI, 3) sub-symbolic AI: classical machine learning, 4) sub-symbolic AI: deep learning.[2] The degree of explainability decreases from level 1 to 4.

(Procedural) Algorithms, such as web crawlers, are easily explainable to the user (stage 1). Symbolic AI is also referred to as good old-fashioned AI in literature (stage 2). Symbolic AI is a part of AI that uses clearly defined, logical knowledge. The explicit knowledge representation is done via symbols. In sub-symbolic AI, however, machine learning approaches use algorithms that learn a task through learning from data. This implicit knowledge is represented by models. Moreover, deep learning approaches with neural networks with many layers, so-called deep neural networks (stage 4), can be distinguished from classical machine learning approaches (stage 3). Deep learning approaches are much more difficult to explain to the user than classical machine learning approaches (Ilkou and Koutraki 2020; Lawson et al. 2021; Akkus et al. 2021). Figure 9 shows the assignment of the 23 possible digital technologies for the realization of the 14 use cases.

[2] So-called in-between methods (cf. Ilkou and Koutraki 2020), i.e., methods between symbolic AI and sub-symbolic are not considered in this step model.

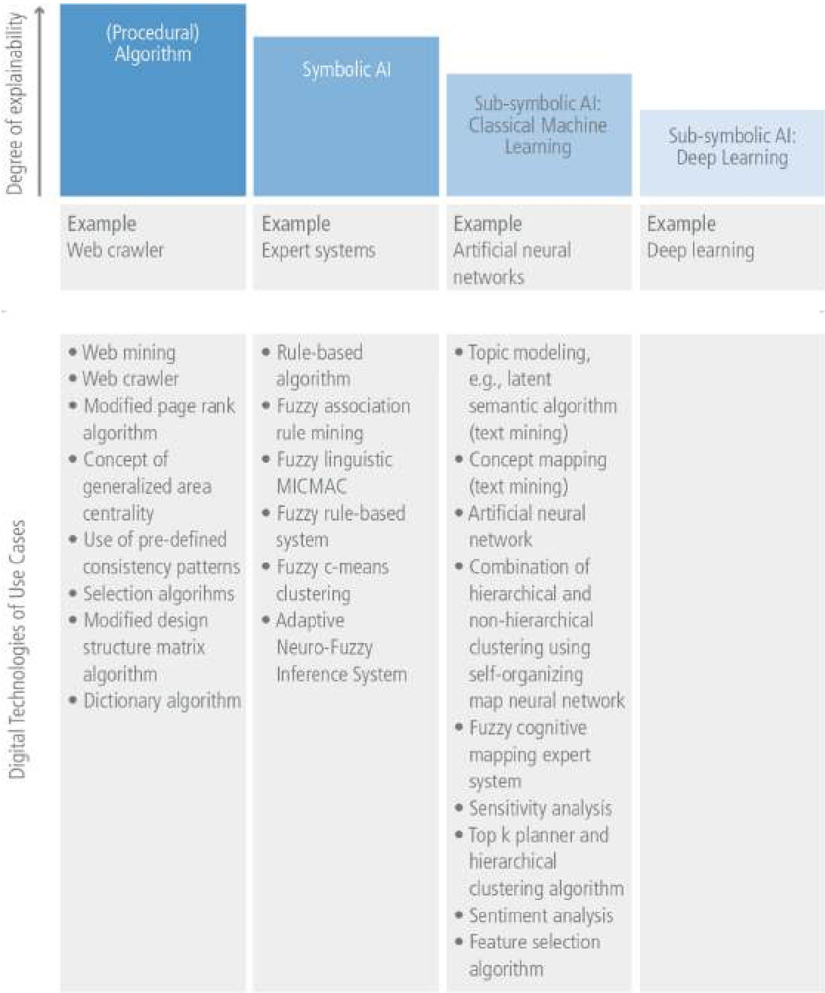

Fig. 9. Digital technologies of use cases assigned to different categories of explainability (own illustration based on Ilkou and Koutraki 2020; Lawson et al. 2021)

Explainability is an essential element of the transparency of digital technologies, a characteristic of socio-digital sovereignty (Hartmann 2020; Hartmann 2022). Regarding the use cases examined, we find that a large proportion of the technologies used can be explained rather easily to the user. These are primarily the eight digital technologies classified as (procedural) algorithms, such as the modified Design Structure Matrix algorithm (Backhaus et al. 2018), and approaches from the field of symbolic AI, such as the fuzzy rule-based system for semi-automatic filling of a consistency matrix (Dönitz and Möhrle 2009). Text mining approaches or simple artificial neural networks for the identification of influence factors or sentiment analysis belong to the field of sub-symbolic AI. These approaches can still be (almost) fully explained to the user, but only with significantly more effort.

4 Discussion

Research Outcome: Our research question was "*which use cases for digital technologies exist in the literature, that could improve the performance of scenario-based foresight?*". Our findings suggest that there are (at least) 14 use cases for scenario-based foresight with digital technologies in the literature as of today. These use cases can be realized using 23 different digital technologies. Currently, digital technologies (still) play a minor role in scenario-based foresight. Digital technologies primarily provide support for tasks in which large volumes of data are processed and analyzed, e.g., in the context of identifying influence factors. Approaches from the field of procedural algorithms and symbolic AI are frequently used. However, approaches from sub-symbolic AI, such as the use of simple artificial neural networks, are also making their entry into scenario-based foresight. Deep learning approaches, however, have not been used to date. Humans continue to be the focal point in the development and interpretation of future scenarios. However, the number of publications on improving the performance of scenario-based foresight with digital technologies has increased in recent years, and so has their significance (Schühly et al. 2020).

For foresight practitioners, the work-in-progress paper provides an initial structuring framework for use cases with digital technologies in scenario-based foresight. It represents a starting point for exploratively identifying new use cases and for classifying them accordingly.

Limitations: The limitations of the work-in-progress paper are closely linked to the chosen research design. First, the selected databases and the manually added conferences and journals may have excluded further conferences and journals with useful papers and articles. Second, the search string itself represents a limitation as the obtained results depend strongly on it. An inclusion of specific steps or activities of scenario-based foresight or the use of more synonyms could yield further interesting use cases. Third, the forward and backward search of the analyzed 26 papers and articles is still carried out right now. Thus, the results could not be included in this paper. The analysis of the results will form the basis for the derivation of new use cases and the adaption of existing use cases for scenario-based foresight with digital technologies.

Implications for Future Research: Limitations of the work-in-progress paper indicate an immediate need for research. In the short term, it is essential to analyze the findings of the forward and backward search for the paper database. Subsequently, those papers should be analyzed as well for relevant use cases. Additionally, it is possible to expand the focus of the literature. E.g., the search term "foresight" can be included in addition to the two directions of thrust for scenario-based foresight as well. Then, it is necessary to analyze which use cases for digital technologies can be transferred from general foresight to scenario-based foresight.

In the medium term, it is useful to derive possible future use cases for scenario-based foresight with digital technologies exploratively. This way, not only existing approaches to improve the performance of scenario-based foresight would be considered, but it would also be able to consider the sheer endless possibilities of emerging digital technologies. On top, an explorative study on use cases that go beyond the current activities, steps, and stages of scenario-based foresight seems promising (Steinmüller 2022; Bauer et al.

2022). Those new use cases could enable completely new methodological activities in scenario-based foresight.

In the long term, the general methodology of scenario-based foresight should be methodically developed further based on the prioritized and selected use cases, in close coordination with the technical realization of those use cases. In this context, it will be important to define which task will be performed by humans and which by digital technologies in the future. This also includes the design of the digital sovereign collaboration of human and technology in scenario-based foresight (Steinmüller 2022; Bauer et al. 2022).

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Human-Machine-Interaction in Innovative Work Environment 4.0 – A Human-Centered Approach

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Abstract. The working environment is constantly changing and companies face the challenge of adapting to new and constantly changing customer requirements. Employees are faced with the challenge of identifying and learning new, helpful technologies and using them in order to achieve efficiency gains and increase productivity. This article addresses the three technologies Artificial Intelligence, Robotic Process Automation and Virtual Reality, which will play an important role in the future of work and will influence the Work Environment 4.0. Artificial Intelligence and Robotic Process Automation relieve employees of repetitive and manual tasks which thus accelerate and simplify business processes. Virtual Reality offers employees new opportunities to collaborate in virtual environments. Instead of performing routine tasks, employees will increasingly promote the use of such technologies in future and orchestrate their application. In addition, it is important for employees to continuously look for new use cases within their own organization and to collaborate with external partners. The article aims to describe the opportunities that arise from the application of the technologies and to explain their effects on the Work Environment 4.0 and the employee.

Keywords: Artificial Intelligence · Robotic Process Automation · Virtual Reality · Human-Machine-Interaction

1 Introduction

In industrialized countries, the competence of employees represents the most valuable resource and locational advantage. Today, however, employees are occupied with rule-based and time-consuming tasks both in the office and on the shop floor. Therefore, they are less able to focus on creative and value-adding tasks. Furthermore, collaboration is needed to connect employees with different domain knowledge and to enable efficient collaboration across departments and organizations for product development.

In order to take advantage of this opportunity, however, companies face the challenge of integrating intelligent and modular solutions into their own business processes. The

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key technologies Artificial Intelligence (AI) and Robotic Process Automation (RPA) play a central role in the new Work Environment 4.0. These technologies take over time-consuming, tedious, rule-based, and monotonous manual tasks from employees and free up employees' capacity for creative and value adding tasks. Furthermore, Virtual Reality (VR) has the potential to enable collaborative work throughout the product lifecycle and to visualize products and processes in real-time. In virtual environments, collaboration enables flexibility and reduces the carbon footprint, as employees do not have to necessarily travel for meetings, nor do they have to work at the same time.

This article presents and classifies three relevant technologies for digital transformation and gives an outlook on the Work Environment 4.0. In addition to the technical explanation, the article describes which competencies of employees are required in future. The scope of the article ranges from office work at the computer to the shop floor of industrial companies (Fig. 1). AI and VR address the shop floor and AI and RPA support employees in repetitive office tasks. Finally, these technologies improve business processes to meet customer requirements. The human orchestrates the use of the three technologies in Work Environment 4.0 and needs background knowledge about the possible approaches and areas of application. At all times, the focus is on the human being that orchestrates the different technologies through a human-machine-interaction approach.

Fig. 1. Overview of relevant future technologies which are described in the article (own representation).

The article begins with an overview on the three future technologies AI (Sect. 2), RPA (Sect. 3) and VR (Sect. 4). Each section is structured similarly and starts with the motivation and introduction. Afterwards the respective technologies are described in detail and possible use cases are explained using examples to highlight opportunities offered by the technologies. The reader should be able to identify areas of application in their own organization, evaluate implementation options, and plan implementation. Finally, the article ends with implications on future of work, a conclusion and outlook on further research aspects (Sect. 5). The aim of this article is to understand the opportunities offered by the three technologies and to be able to better classify them. All of the technologies presented have the potential to optimize processes and to shape the Work Environment 4.0. Furthermore, there are also organizational changes and changing requirements for employees in Work Environment 4.0.

2 Artificial Intelligence

2.1 Motivation and Introduction

Since computing hardware has improved in the 2000s, AI has started to influence many aspects of daily life and is making rapid advancements e.g. finding anomalies in machine behavior or optimizing business processes in shop floor and office work. AI is broadly usable and a technology which changes work environments and will be able to shape the workplace of tomorrow.

In this section we define AI and describe the fields of application of AI for practitioners in the Work Environment 4.0. We also describe technologies that are researched right now and will likely have a significant impact on the workplace. Since employees in various departments can benefit from these technologies we will present use cases for both work on the shop floor as well as work in the office. Finally, we will give an outlook on the implications of these technologies for the human being.

2.2 Theoretical Background

AI has the ability to solve complex problems. For this purpose, methods are used that are similarly used by humans [1, 2]. For example, AI can communicate with customers, help to identify anomalies in data, read documents, send out digital ads or predict scenarios.

There are numerous definitions for AI e.g. weak- or strong AI. Weak AI focuses on solving specific existing problems and on one aspect of mental function. Strong AI is an approach that tries to reproduce and imitate the human being e.g. empathy [3]. This article focuses on weak AI, as it is the most commonly used in practice.

Machine Learning (ML) is the area of AI that is mostly associated with the term today. In the context of Smart Manufacturing and Industry 4.0 ML plays a crucial role in the intelligent usage of data and thus in the modern industrial process environment. The amount of data being generated in the processing industry is increasing rapidly. ML algorithms lead to an effective and efficient use of those data quantities. ML is at its core about learning from data and can be defined after the general learning task as: “A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P, if its performance at tasks in T, as measured by P, improves with experience E." [4].

Deep Learning as a subset of ML refers to neural network architectures that use an input and output layer of neurons as well as multiple hidden layers [5]. This form of ML has gathered a lot of interest due to the increased performance of computing hardware (Graphics Processing Units, Neural Processing Units, dedicated Field Programmable Gate Arrays) and the resulting feasibility of the execution of more sophisticated artificial neural network architectures e.g. Convolutional Neural Networks (CNN), Recurrent Neural Networks, Generative Adversarial Networks, Transformer Networks, etc. ML can be divided into unsupervised, supervised and reinforcement learning. The approaches behind these three categories are explained after introducing the concept of training.

The AI system is supposed to learn a generalized rule or behavior from a dataset. Thereby, the ML model achieves to accurately predict on new and unseen sets of data. In principle, two stages of model usage are distinguished: training and inference. Training in this context means the process of building or shaping the model. In ML, many kinds of models can be used, e.g. Decision Trees, Regressions, Support-Vector-Machines (SVM) or Artificial Neural Networks. The second stage in ML is model inference. At this stage, an already trained model is executed in order to accomplish the task. Therefore, the model works on test data or with live data. In some applications data is still used for further training, in others it is discarded after model execution. Often the decision-making process of trained ML models is unclear and difficult to verify due to the black box character of ML methods. For example, a model that identifies bananas does not look for a curved yellow object, but only for a blue sticker. Recent developments in the field of explainable AI try to alleviate some of these challenges [6].

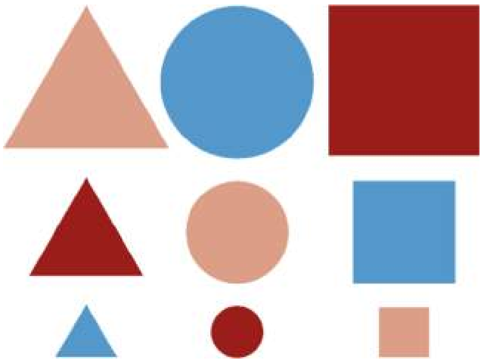

Fig. 2. Sample input data for a ML model (own representation).

One approach used in ML is unsupervised learning which uses unlabeled data. This means that nothing is known except for the input. The resulting model can be used to identify patterns or groups within a data set. This step is defined as knowledge discovery [7]. As the example of input data in Fig. 2 shows, a model for unsupervised learning could cluster in terms of many different metrics, such as size, shape or color. Nevertheless, a model could also identify squares and circles that are point-symmetric.

In supervised learning, the raw data has been labeled before training. Therefore, the trained model has to learn a mapping between input and output, i.e. shape, size and/or color of the input [7]. However, the act of labeling can be very time-consuming since often it is still a manual task involving human labor.

Reinforcement learning is another approach and in contrast to unsupervised and supervised learning, the feedback to the model is punishment signals or reward. The algorithm must find the actions which maximize its incentive function [7]. For example, when playing chess, AI has to take actions that lead to reward and finally to success. The environment is often represented by a Markov decision process. Reinforcement learning is used to solve many problems that are analytically infeasible [8]. When training a reinforcement model, we try to find an optimal policy for an agent, to find an appropriate action in any given state of the environment to maximize the reward and to not get stuck in local optima.

In the following section, we will present some technologies that are likely to reshape Work Environment 4.0.

Human beings communicate and share knowledge using written and spoken language. Oftentimes it takes a whole childhood to learn how to form words, associate words with things, form sentences, learn how to read and how to write. Enabling machines to work together with human is one of the big aims of current AI-research in the field of Natural Language Processing (NLP). NLP focuses on solving tasks involving the human language e.g. by analyzing syntax, semantics and context. BERT (Bidirectional Encoder Representations from Transformers) [9] and all its derived versions, GPT (Generative Pre-trained Transformer) [10], XLNet (Generalized Autoregressive Pretraining for Language Understanding) [11], PaLM (Pathways Language Model) [12] enable machines to perform increasingly well with a multitude of difficult NLP tasks.

Practical applications in the context of NLP tasks range from the processing of text using Optical Character Recognition (OCR), handwriting recognition, text summarization, text prediction and Natural Language Generation (NLG), chat-bots, document understanding, Natural Language Understanding (NLU) or text to image generation.

Furthermore, generative models, in particular "Generative Adversarial Networks" (GANs) enable the generation of realistic synthetic data in a variety of fields, finding application e.g. in photo realistic image generation, video generation or music generation [13]. Recent image generation models from OpenAI (DALL-E, DALL-E 2) [14] and Google's Imagen [15] enable the creation of artistic and photorealistic images using simple text-based prompts as input.

With the introduction of CNNs and their improved architectures image classification tasks can be solved on a level surpassing human ability [16].

2.3 Application

Processes are digitalized and automated in almost all areas within an organization. Mature technologies which come from the field of NLG, NLU and NLP, e.g. OCR and handwriting recognition can speed up this process even further. Furthermore, AI influences jobs which have already been digitized. For example, product development teams with jobs in design and engineering, simulation and programming may use AI assisted systems and enhancements which will lower entry barriers, decrease cycle times and time to market, speed up decision making processes and increase customer satisfaction [17].

AI assisted engineering also increases the potential for more complex products and cost savings in production as well as for a sustainable climate [18]. Repetitive and pattern-based digital tasks in engineering can be performed faster by using algorithms which employ deep neural networks [19].

Methods such as SVM, Naive Bayes and k-nearest Neighbor are already used in industry to ensure quality assurance in production [20–22]. In addition to the early identification of quality problems, it is also crucial to initiate process improvements immediately and to transfer findings to other production lines or the supplier network in order to reduce quality costs. Transfer learning offers the opportunity to apply existing ML models to comparable problems, thereby exploiting synergies and saving development effort [23].

In the last 50 years, with the emergence of new data processing capabilities, there have been big changes in the handling of machine maintenance and prognostic health management. The integration of large-scale sensory data feedback (big data) as well as edge devices or smart sensors systems on the shop floor enable production data to be monitored and stored in real time [24].

Data Mining methods facilitate shop floor data association analysis [25].

Additionally, wireless communication technologies enable distributed manufacturing resources to collaborate with each other. By integrating the physical and the information layer, the concept of the “Industrial Internet of Things” (IIoT) becomes more relevant. Industrial big data is therefore particularly concerned with the meaning of the data and its association with failures and value creating mechanisms [26].

This means that the analysis of industrial big data requires domain knowledge, for example, in failure mechanisms, process knowledge etc. Fault diagnosis and health assessment models usually rely on accurate, clean, and frequently adequately labelled training data, thus making the data quality an essential aspect of the industrial success of these solutions [27].

The use of digital twin technologies further increases the possibilities for optimization, autonomous decision-making as well as increased transparency for management [28].

3 Robotic Process Automation

3.1 Motivation and Introduction

Today employees are responsible for numerous business processes and have to perform manual and tedious tasks, whereas creative and value-adding activities like the development of innovative products are often neglected. In addition to processes on the production line, activities carried out on the computer offer further potential for automation. Organizations may achieve faster and more accurate business processes by using the future technology RPA. Furthermore, employees may focus on customer requirements and the development of new products and services to ensure competitiveness. RPA is of particular importance in office work to achieve efficiency gains for organizations and to respond promptly to customer needs and to secure a sustainable competitive advantage.

The traditional automation of processes is carried out by Business Process Management Systems (BPMS) which are often referred to as workflow systems. Such workflow systems require the programming of interfaces as well as the adaptation of the IT architecture. These solutions, known as heavyweight IT, are invasive and fully integrated. "Heavyweight IT denotes the well-established knowledge regime of large systems, developing ever more sophisticated solutions through advanced integration." [29]. In contrast, RPA depicts lightweight IT and represents a non-invasive option for digitizing and automating as business processes are automated without changing the existing IT architecture [29]. The term RPA is often associated with robots that perform manual operations such as assembly tasks and relieve humans of their daily workload. RPA technology, however, addresses repetitive time-consuming tasks that are performed by humans on a computer. Thus, robotic in this context refers to installable and flexible computer software which supports employees in daily tasks like data transfer or data manipulation [30].

RPA has become increasingly popular in recent years and is now used in various industries and companies. In an empirical survey, 400 decision-makers from companies in the US, UK, France and Germany with at least 50 employees were questioned. The survey examined the use of RPA solutions. According to the survey, only 33% have already deployed RPA solutions, and 31% intend to do so in the next 12 months. Accordingly, the greatest opportunities are seen in the area of customer experience, as 39% of those surveyed assume that process automation will have a positive effect on this area of the company [31]. Today companies have access to a wide range of automation software to develop RPA solutions like the three leading platforms: UiPath Studio, Automation Anywhere and BluePrism [32].

In this section we describe the RPA technology and show possible use cases in office work as well as the combination of RPA and AI.

3.2 Theoretical Background

There are numerous definitions of RPA in the literature. IEEE Corporate Advisory Group (CAG) emphasizes that a RPA solution is software: "A preconfigured software instance that uses business rules and predefined activity choreography to complete the autonomous execution of a combination of processes, activities, transactions, and tasks in one or more unrelated software systems to deliver a result or service with human exception management" [33]. The Institute For Robotic Process Automation (IRPA) also defines RPA as a software solution: "Robotic process automation (RPA) is the application of technology that allows employees in a company to configure computer software or a "robot" to capture and interpret existing applications for processing a transaction, manipulating data, triggering responses and communicating with other digital systems." [34].

RPA solutions are based on the three different technologies: workflow automation, screen shaping, and AI. Workflow automation automates data transmission and the processing and routing of data and files. Screen shaping includes all processes for reading text from computer screens and further processing these data in other software. AI enables organizations to transfer human learning and automating more complex business processes [35].

RPA software applications combine these three technologies so that time-consuming, recurring and error-prone tasks can be performed in Work Environment 4.0. The RPA solution is faster than the corresponding manual process by humans and the proesses is also logged. This means that all steps performed in RPA are always traceable and ensure a higher quality in terms of results.

RPA operates on the user interface of a computer and aims at replacing people [36]. Likewise, RPA is known for the creation of simple procedures which do not necessarily require programming, but can be created with drag and drop functions. However, programming skills are necessary to implement more complex procedures [37]. To get RPA running in an organization a configuration and scripting of this incident is required once. After that, the routine can run permanently or may be scheduled to run e. g. daily at the same time.

Using RPA hardly affects the existing IT infrastructure in the company because RPA works on the user interface [30]. The operation of these routines is simple. If errors occur during the execution of the automated process, specialized personnel needed quickly to identify the error and possibly adjust the configuration. In this respect, RPA is only suitable if the rules or the working environment at the user interface do not change constantly. Thus human errors can be avoided with RPA, e.g. due to the lack of concentration and motivation. Thus, RPA has a wide range of applications in companies and organizations for process automation and acceleration as well as an expansion of capacity with high quality in the completion of tasks. RPA, however, cannot replace a human per se; rather, RPA can be used to relieve people of usually quite simple and often very monotonous and tedious tasks on the computer so that they can attend to more difficult tasks or other activities.

Companies looking for RPA opportunities have to consider several criteria for identifying the processes best-suited for RPA. A four-step approach which supports companies to evaluate process eligibility is given in literature. According to this approach, automation only suits rule-based processes that require manual interaction with a software application [38].

3.3 Application

In the literature, numerous case studies are described in various industries. Typical tasks that are often replaced by RPA software tools are logging into applications on the Internet or from Enterprise Ressource Planning (ERP) providers, merging statistical data from different IT systems and preparing these data as a graph or report in a program, any kind of copy and paste activities for data transfer, saving, renaming and moving documents, executing simple if-then rules. Likewise, bots can perform calculations as well as generate and send emails even with attachments [39].

Figure 3 lists further processes that can be automated by RPA.

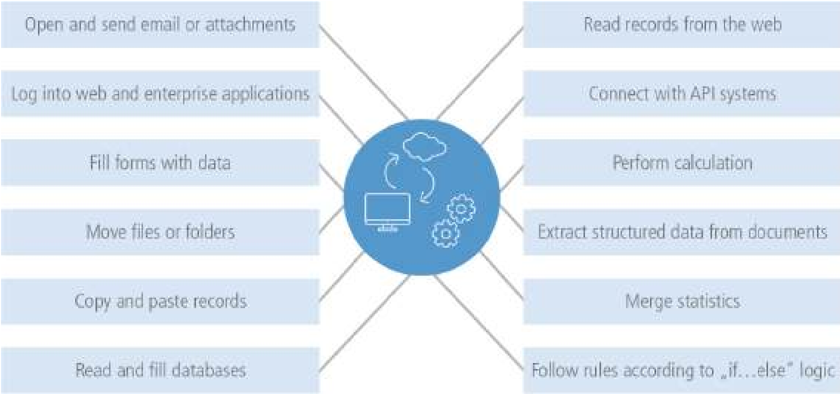

Fig. 3. Process steps that are particularly suitable for RPA implementation (own representation based on [39]).

RPA technology has the potential to automate business processes in quality management and to ensure product compliance. In a case study, Mercedes-Benz AG achieves a faster and more accurate business process, saves 5.075 FTE (full-time equivalents), and increases product quality [40].

A business process outsourcing (BPO) service provider automated the invoicing process so that over 21% more cases can be processed by employees. Thus, productivity (measured by cases processed per employee) increases as the RPA solution processes multiple cases simultaneously [41]. Furthermore, RPA may be used in the field of audit [42], finance [43], procurement [44], customer service [45], among others.

In contrast to these advantages, there are risks that need to be managed. Immature RPA solutions carry the risk of decreasing productivity and additional manual steps, and increase error rates [46, 47]. In addition, stuff members might reject RPA solutions due to their fear of job losses resulting from the personnel savings which are achieved incidentally. These employees are then freed up for more creative and challenging activities. At an early stage, however, companies may have to prepare these employees for new fields of activity in Work Environment 4.0 through training.

Furthermore, smooth operation of RPA software tools can only be guaranteed, if these solutions are regularly updated and checked. Likewise, when scripting the routines, engineers have to make sure that they are programmed as robust and stable as possible. User interfaces that do not change often are an essential prerequisite for stable running bots, as any change usually means adjustments in the program. Such adjustments and also errors that occur in bots during operation require skilled personnel who can intervene quickly and at any time.

The more intelligent an RPA solution is, for example by using OCR for automated reading and processing of delivery bills, the more complex and demanding the scripting of the solution is. In some cases, this requires adjustments to the process and also specialized personnel who can implement these solutions [48].

Since RPA can be implemented easily on a company's own computer, in some cases, even without IT experts, RPA also offers the potential to increase shadow IT in the company, especially in the specialist departments. This aspect, in return, can have a negative impact on IT security and operation as well as on adherence to compliance guidelines [37].

The following Fig. 4 shows the key advantages of RPA implementations for companies and organizations.

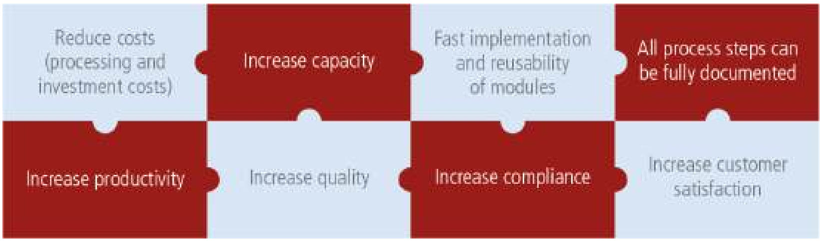

Fig. 4. Key advantages of RPA implementations (own representation).

RPA software will become even more powerful with the further development of functions that incorporate AI. RPA software providers are already offering such functions that play a central role in Work Environment 4.0.

ML is another growing area of AI related to RPA. This area uses algorithms to generate artificial knowledge from existing data so that certain patterns are recognized. The bot learns from these patterns and then applies this knowledge to new data sets. A typical application here would be a bot that has learned to distinguish invoices from other documents, scans them by using OCR and enters them correctly into the company's ERP system.

NLP functions enable bots to copy texts and insert individual words in other places. The bots, however, are not yet able to understand these words. Extensions that can be expected in this direction in the future fall into the areas of NLU and NLG. Then a bot will also be able to understand texts and generate its own texts. This is also referred to as "social robots" or "digital assistants". These will then be able to simulate human judgment [30].

RPA is also used in combination with Process Mining (PM). PM enables companies to analyze and improve their existing processes with the help of accumulated data on the computer. Thereby, transaction data collected in the form of log files is read from the company's existing systems, such as ERP and Customer Relationsship Management (CRM) systems, and imported into process mining software. If the data is factually assigned correctly, the PM software analyzes the data and presents it by means of a model of the processes that actually took place. In addition, dashboards can be used to display various key figures such as the lead time and statistics for the process. These figures provide information, for example, about all process variants that have occurred or about existing bottlenecks in the process. On this basis, it is relatively easy to define and automate a new target process. In addition, processes executed by bots also generate transaction data, which can also be analyzed and subsequently improved by PM.

For automation, workflow software can be used for processes with an enormously high degree of standardization and high case frequency, or RPA software for a medium degree of standardization and medium to high case frequency [30].

4 Virtual Reality

4.1 Motivation and Introduction

Global events like the pandemic put a spotlight on remote work and on the demand for virtual education and collaboration across departments and organizations. Embedding the human user into a virtual learning environment can lower the inhibitions and fear through the possibilities of free experimentation and the benefit of making errors in virtual environment without the risk of damage or financial loss. Tutorials can be set up individually, tailored for the learner's level of knowledge. More advanced applications are the training of workers for the configuration, operation and maintenance of products, machines or production plants.

VR in engineering encompasses the whole product life cycle and supports it with a variety of applications like the design review during the product development process, production planning for manufacturing or training applications just to name a few.

The concepts, methods and systems are all well known for years, but struggle to get adopted, especially in small and medium-sized enterprises. We want to give an insight into current research and will look at VR from a technology perspective, but also from the engineer and worker perspective.

In this section we describe the opportunities of VR along the product development process and present a specific education use case.

4.2 Theoretical Background

According to the Reality-Virtuality Continuum [49], two environments are distinguished: On the one hand, there is the real environment which consists of real objects and illustrates the real-world and on the other hand, there is a virtual environment with virtual objects which are monitor-based or immersive. Mixed-Reality (MR) environment is in between and comprises real objects and virtual objects. The term immersion refers to the feeling of being in VR. According to studies [50], immersive technologies are suitable for communication and understanding of emerging products.

The product development process controls and manages all activities linked to the aim of developing a product that meets customer requirements and also fulfills the organization's financial and technical conditions. During the product development, the development status must be continuously checked and tracked. Therefore, humans need to work together in interdisciplinary teams and in a collaborative and virtual environment.

There are a few tools that provide the classic range of functions of a design review tool e.g. IC.IDO from ESI and CMC ViewR from CMC Engineers. Both tools offer a wide variety of data and communication interfaces in order to be able to visualize CAD data in immersive VR hardware systems. Then engineers can validate the CAD design with various tools such as measurement tools, cutting planes, drag-and-drop interaction or a physics simulation of the model components [51].

In contrast to these tools, TechViz is a middleware that extends Computer-Aided Design (CAD) software and other 3D-Software and taps the data as an Open Graphics Library stream. Since TechViz can display data in immersive VR hardware systems [52] its focus is on the design review application.

In the field of virtual commissioning, research and development at manufacturers of automation solutions exists. This includes, for example, Simit [53]. Virtual commissioning generally facilitates extensive validation of the planning data during product development, especially in individual machine construction. On the other hand, however, virtual comissioning presents an enormous effort as it entails the effort to create functional virtual models, to model the dynamics and kinematics, to parameterize the interaction with scripts and the real-time simulations.

The automation of the creation of virtual functional and interactive machine models is a research field that has been addressed at the Institute for Information Management in Engineering (IMI) for several years [54]. This is the basis for all Virtual Engineering (VE) methods like design reviews during product development, the virtual commissioning of production lines, training applications, maintenance simulations, material flow simulations and much more. VE as a new working method in product development makes it much easier for engineers and product managers to validate the partial development or interfaces between groups, departments and organizations. In addition, Software in the Loop (SiL) and Hardware in the Loop (HiL) enhances work steps that can already begin with virtual instead of real components.

In order to consistently validate Mechanical Computer-Aided Design (MCAD) and Electronic Computer-Aided Design (ECAD) as well as programming, automated virtualization systems must integrate all planning data into a Virtual Twin (VT) of the machine, system or integrated production line at the push of a button. Generic intelligence is automatically added using Semantic Web technologies, enabling complex interactive models that can be used for training, monitoring, and many other applications beyond just validating design data [55]. In order to achieve this high degree of automation, geometry analysis algorithms are used to capture as much intrinsic knowledge as possible from the MCAD and thus automatically parameterize kinematic simulation. Such interactive simulation modules are important to simulate the behavior of machines and processes and to give the user extensive interaction options. Another aspect is the automated aggregation of all knowledge from the planning data, especially the merging of the component data in MCAD and ECAD.

The software system used to implement the above-mentioned subsystems, data interfaces, interactive simulations and VE applications is the VR authoring system PolyVR. This open source project was initiated in 2009 at the IMI, Karlsruhe Institute of Technology [55, 56].

The automated virtualization is a fundamental game changer for design reviews with functional models up to virtual commissioning. But this method also greatly simplifies the authoring of more advanced applications that can use those functional machine models for software and HiL, operation and maintenance training applications and VTs for configuring and monitoring. In this regard, the impact of optimizing data interfaces, simulating as many aspects of machinery as possible and interactively, goes way beyond the product development process. For engineers in the Work Environment 4.0, this offers a new horizon of possibilities, especially to create and deploy VR-supported applications like training and monitoring in production settings and not only as demonstrators in academic settings.

4.3 Application in Tunnel Boring

In this use case, we will show how the implementation of a VT coupled with a physical setup can help human learners to understand processes in a quicker time frame and more controlled environment (Fig. 5). In this MR training setup, a tunnel boring machine was replicated virtually and coupled in a HiL approach to behave similarly to the real counterpart. While the human operator still stands in front of a physical control panel on the construction site, the tunnel boring machine itself is physically missing and only digitally existing as a VT. The logic control program of the machine is used to drive the virtual machine. By running and communicating with the control software in real time, exactly as it would run in the physical environment on site, we gain the possibility to design virtual scenarios for individual learning settings. These user specific scenarios and stress situations can be deployed to emulate failures during the process without the fear of harm for either the machine or the human worker. Different solution approaches can be discussed as well as effortlessly and repeatedly tried during the training by the learner to see how the machine will behave according to varying control inputs.

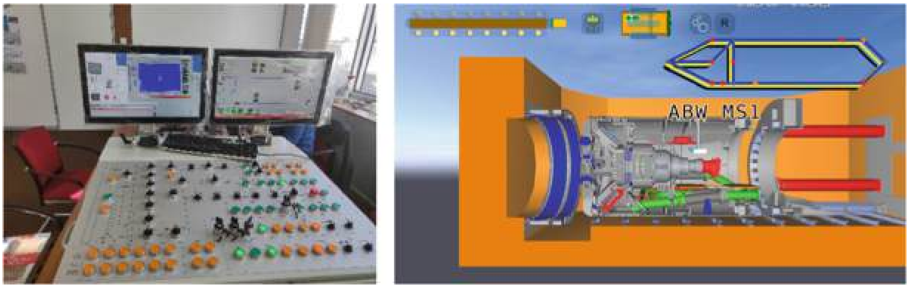

Fig. 5. On the left: Physical operator terminal, steering panel and display for showing system status. On the right: Visualization of the virtual tunnel boring machine (own representation).

The simulator consists of three parts (Physical Control Panel, Programmable Logic Controller (PLC) Program, Machine Simulation) which are subdivided again into further modules.

The physical control panel with two attached displays is the Human Machine Interface (HMI) which the operator faces on a construction site to control the tunnel boring machine. This is necessary for both the real machine as well as the simulator to guarantee that the learner has the same haptic feeling and visual cues just like on site. While within the virtual simulation a virtual representation of the control panel is possible and implemented as well, the benefits of a real control station already imitate the feeling of familiarity of the machine operators.

The PLC program is between the physical control panel and the simulation and is responsible for the behavior of each moving component of the tunnel boring machine.

In this program the data from all the sensors are consolidated and processed. Depending on set targets and safety limits, specific behavior (e.g. power cut off, or safety valve position) is programmed into the software to protect both the machine as well as human personnel in the vicinity. Reactional behavior according to the operator's input is also commanded by this software (e.g. variable pump output, valve position, motor speeds).

On the virtual side of the simulator, the virtual representation covers the tunnel boring machine up to a certain degree of detail (Fig. 6). In the best case of implementation, the machine would be virtually identical to the real counterpart but due to typical restrictions such as computational power of the simulators and the required real-time capabilities of the simulation only a scaled down VT is deployed in this use case.

The VT of the tunnel boring machine consists of the machine's visual representation, which is derived from the CAD-model. This model's geometries are positioned in real time to show the current position and direction in 3D-space as well as to depict functionality such as cylinder expansions of the cutting head's steering capabilities and it's cutting wheel speed. To calculate these parameters, the virtual simulation is implemented on a physically based model of the machine. The modular architecture of the simulation contains the following subsystems of the tunnel boring machine: The propulsion of the whole machine is handled by hydraulically actuated cylinders which have pressure sensors to show how much force is applied to drive the boring machine into the earth.

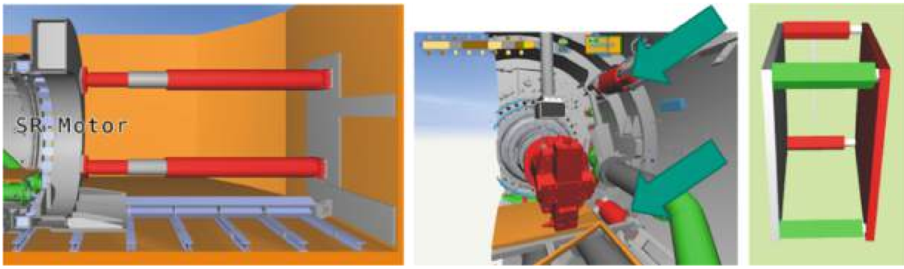

Fig. 6. On the left: Propulsion cylinders in red. In the middle: Directional steering cylinders marked with arrows. On the right: Visualization of the underlying physics simulation of the steering cylinders (own representation).

The movement speed of the whole machine results from the interplay of how much earth is removed in front of it and how hard these cylinders press the machine into the earth. The cutting head's parameters define the behavior of the boring machine such as the direction (controlled by hydraulic steering cylinders) and the rotational speed of the drill. The quicker the head spins, the more volume is removed by the boring machine. The loosened and disheveled sediment is transported out of the tunnel by a pipe system which provides the transport medium to the cutting head. The back flowing water mixture is filtered, recycled and moved by pumps and controlled by valves. After the maximum length of one tunnel segment is reached, the propulsion cylinders are retracted and a new segment is added to the setup (Fig. 7).

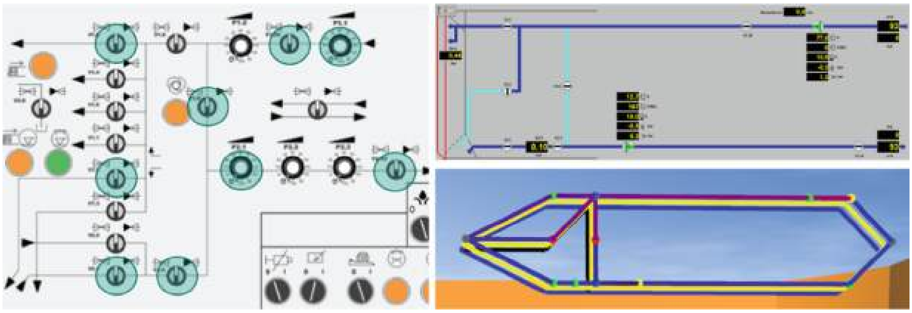

Fig. 7. On the left: Operator panel of the water cycle, the deployed valves and pumps are marked in green transparent cycles. On the right: Top: Operator visual feedback display of the machine's water cycle. Bottom: Virtual display of the water cycle simulation (own representation).

By means of this simulator, the learning operator gains a tool worked out with all the necessary components, safety settings and machine behavior which mirrors real working situation on a construction site. Thereby, the operator is able to concentrate on the control strategies without the possibilities of real damage to physical parts or human co-workers.

5 Conclusion

The future of work will change continuously and the three technologies presented in this article may increase productivity and efficiency of organizations. The requirements on employees at shop floor and office work will constantly change. At office work, efficiency increases and productivity gains will result from AI and RPA. Instead of processing rule-based tasks, employees will see themselves in the role of identifying rule-based and monotonous work themselves and automating it using suitable RPA and AI solutions. In addition, cross-departmental and cross-organizational processes must be optimized, digitized and finally automated. Constantly changing external requirements require continuous adaptation of business processes and thus adaption of RPA and AI solutions. Employees need technical know-how and process knowledge to plan, build, run and manage automation solutions.

In addition, the use of VR enables new possibilities for collaboration. Collaborative working is becoming an essential part of our everyday lives, with multiple individuals organizing themselves into teams to jointly develop products and services. The increasing networking of individuals is not only influencing our social life but therefore also our everyday work. Tomorrow's engineer will need to understand and handle much more complex systems and tools to cope with the ever increasing demands and complexity of product development. These methods will not focus on simplifying modeling and planning as CAD systems do, but rather on simulations and AI to enable much faster development, much more advanced optimizations and much more efficient validation iterations.

It is necessary that employees get to know the three proposed technologies and acquire knowledge. The further development of the three technologies is progressing and thus even more use cases will be possible in the future that will help organizations to maintain their competitiveness. RPA and VR solutions will become more intelligent through the use of AI and their areas of application will expand as well as improve their performance.

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Collaborative Work Enabled by Immersive Environments

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Abstract. Digital transformation facilitates new methods for remote collaboration while shaping a new understanding of working together. In this chapter, we consider global collaboration in the context of digital transformation, discuss the role of Collaborative Virtual Environments (CVEs) within the transformation process, present an overview of the state of CVEs and go into more detail on significant challenges in CVEs by providing recent approaches from research.

Keywords: Collaborative virtual environments · Collaborative workspace · Extended reality · Remote work

1 Global Collaboration in the Context of Digital Transformation

Collaborative work is an essential part of our professional life, where several individuals organize themselves into teams to work on joint projects. The original form of collaboration is the social face-to-face collaboration, where individuals or groups meet up co-locally [46] to interact and share information. A collaboration always requires participants as well as an environment where it takes place. As a result of globalization, the work in companies, institutes, and educational facilities increasingly involves stakeholders and interdisciplinary experts from all around the world. Therefore, the usage of established remote collaboration technology has significantly increased in recent years: ZOOM 2000% from Dec-2019 to Mar-2020, Cisco WebEx 250%, and Microsoft Teams 600% from Dec-2019 to June-2020 [23]. Thus, it is not a big surprise that global companies and researchers are paying more and more attention to the field of remote collaboration [3,27,114] aiming to improve the way we work together. To address the effects of globalization, Collaborative Virtual Environments (CVEs) have been implemented and are currently used. In such immersive environments, the participants can virtually join from their remote locations and together conduct collaborative work within the shared virtual environment. In 2021 over 171

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commercial Mixed Reality (MR) CVE solutions were identified as presenting solutions for the Design Review, Training, Assistance and Construction application domains [112]. In research, a growing interest in MR collaboration, in particular remote MR collaboration, can be observed since 2012 [3,27,114]. This correlates with the increasing affordability of MR technology and accessibility of MR development tools, and also emphasizes the growing need for remote collaboration solutions [27,114].

1.1 The Interplay of Digital Transformation and Remote Work

Digitalization has a great impact on the way we work together [78]. The digital transformation facilitates new methods for remote collaboration while shaping a new understanding of working together [95]. To process collaborative work within Collaborative Virtual Environments, the involved collaborators and their work environment containing the required tools and artifacts need to be digitalized. The virtualization of collaborative tasks greatly benefits from the ongoing "Industry 4.0" movement involving Cyber-Physical Systems (CPS), Internet of Things (IoT) and Internet of Services (IoS) technologies which are relying on data collection and digitalization of the involved physical artifacts. The digitalization of the artifacts goes to the extent of Digital Twins (DTs) being continuously synchronized real-time representations of the physical objects within the Virtual Environment (VE) [74].

The other way around, collaborative networks are considered a core driver [9] and remote work an accelerator [23,25,53] for the digital transformation. The "Industry 4.0" concepts strongly rely on new organizational forms, mechanisms and processes with a collaborative nature in the main dimensions (i.e. vertical integration, horizontal integration, through-engineering, acceleration of manufacturing, digitalization, and new business models) in which collaboration related issues could be identified [9].

From the social perspective, the demand for more flexible work in terms of work location and work time is increasing and the lockdowns during the Covid-19 pandemic showed that remote work is possible with today's technology in many areas [25]. As a result, the pressure on organizations is increasing to adapt and implement new ways of working [54]. Current research concludes that remote work will be accepted as a common way of working[1] complementing the ongoing trends from tele-medicine and tele-learning. As a side effect, the implementation of remote work will accelerate the digital transformation [40].

1.2 Effect of the Covid-19 Pandemic on Remote Collaboration

The Covid-19 pandemic plays a big role in the transformation of work and affects how collaborative work environments should be developed to meet the changing

[1] Gartner CFO Survey Reveals 74% Intend to Shift Some Employees to Remote Work Permanently: https://www.gartner.com/en/newsroom/press-releases/2020-04-03-gartner-cfo-surey-reveals-74-percent-of-organizations-to-shift-some-employees-to-remote-work-permanently2.

requirements. Recent research shows that Covid-19 serves as an "accelerator", "catalyst" or "booster" for the ongoing transformation of work [23,25,53]. At the beginning of 2020, governments imposed lockdowns forcing public and private organizations to restructure their work processes and ensure safe work for their employees. Edelmann et al. [25] have researched how Covid-19 has affected work in the public sector since 2020. They observed a transition from traditional work in the offices to remote work in home offices during lockdowns and concluded a rapid and far-reaching change of work in organizations from all domains. To ensure safety, the workplace structure should change and have less populated work environments [23]. The pandemic has opened opportunities for changing traditional work to remote work, which became an important measure to combat Covid-19 while ensuring service delivery[2]. For instance, the "boost" of remote work was observed in Austria: while remote office was used in 75% of the companies by a very privileged group of employees, after the onset of Covid-19 regulations in 80% of the companies most of the employees worked remotely, and 85% were utilizing tools for remote collaboration [48]. Before the pandemic, remote work from home was equated with "being on holiday" but in the situation during the Covid-19 lockdowns, the employee performance was perceived as equivalent to being in the office [25]. Remote work brings benefits of flexibility, greater concentration, better work-life balance, and a perceived productivity increase [25,48]. On the other hand, it also brings disadvantages for remote collaborators like long online meetings, information overload, and difficulties with team coordination. Nevertheless, a large majority of employees wish to continue working remotely more extensively in the future [25,92] which emphasizes the importance of the digital transformation of work. In fact, digital transformation requires more than just the application of digital technologies. The success of the digital transformation of work also highly depends on the adaptability of people [23]. Also, a change in the composition of required skills of the collaborators, like independent working and self-management for the employees, as well as providing respective learning opportunities and basic structures for remote collaboration can be perceived [25].

2 Collaborative Virtual Environments

2.1 Immersive Technologies

CVEs belong to the family of immersive technologies. By immersive technologies we refer to Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) technologies, also grouped into a generic term, eXtended Reality (xR) [88].

Milgram et al. illustrate the different concepts for immersive technologies with a simple diagram called the reality-virtuality continuum [71]. Figure 1 locates VR, AR, and MR within this continuum. Between the two extremes, the real and virtual environments, there are infinite combinations that are grouped

[2] EIPA, Forschungsberichte zur Arbeit im Homeoffice: Eine kritische Übersicht: https://www.eipa.eu/blog/forschungsberichte-zur-arbeit-im-homeoffice/.

under the umbrella term MR. Particular forms of MR are thus AR and Augmented Virtuality (AV). AR is defined as a computer-assisted augmentation of reality perception by superimposing virtual objects or additional information. AV, on the other hand, allows the developer to enrich the artificial world with real information. According to the continuum, VR is defined by its fully simulated environment [37]. Sherman and Craig [97] give a definition for VR as: "a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation". The essential properties of VR are immersion, interaction, imagination, presence, and intelligence [37].

VR systems, designed to provide a sense of presence, consist of a number of hardware devices and software. The hardware typically consists of visual and audio output, a tracking system, powerful graphics computers, and in some cases, may have haptic feedback. The visual output comprises three-dimensional screens that can be attached directly to the user's head (called Head Mounted Displays (HMDs) or VR headsets, see Fig. 2) or a stationary screen such as a projection-based Powerwall or a Cave Automatic Virtual Environment (CAVE) (see Fig. 8). AR systems use mainly so-called see-through headsets (see Fig. 2 on the right) or hand-held devices (smartphones, tablets). The required software is based on VR-capable graphics engines or scene graph systems to execute the applications. This task could also be performed by a VR authoring system, which has the additional task of building the scene and implementing the application logic. Depending on the use case, 3D modeling tools can also be applied to create the 3D content. To realize CVEs the VR software needs a special collaboration module to enable communication and synchronize the user interaction with the VE. In this way, the VEs can be experienced by more than one user and collaboration between the users can take place. At this moment, we are talking about collaborative VEs or CVEs.

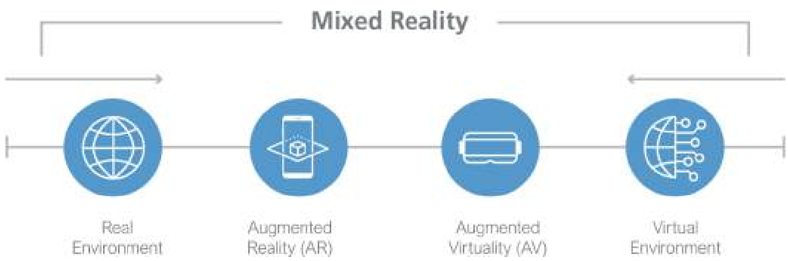

Fig. 1. Reality-virtuality continuum. Source: own representation based on *Augmented reality: a class of displays on the reality-virtuality continuum.*, by Milgram, 1995.

Fig. 2. Concept of a CVE with mixed collaboration modes and xR technologies. Left: Avatars of remote collaborators participating via VR HMDs or a CAVE. Center: Collaborator participating through a video call on their desktop PC or hand-held device. Right: Present (co-located) collaborators using AR HMDs. Source: own representation.

2.2 Dimensions of Collaborative Environments

Collaborative Environments (CE) occur in many varieties depending on the type of collaboration itself and depending on the function it shall fulfill. For instance, the collaboration can take place at different times or involve different locations. CEs can enable various collaborative tasks like group authoring or virtual meetings. The matrix in Fig. 3 shows the dimensions of collaborative work and is an extension of the groupware matrix by Johansen [46].

The matrix of collaborative work classifies group work into six categories along the dimensions of space, time, and xR (see Fig. 1). In the dimension of space, a *co-located* collaboration takes place at the same location for all collaborators, while in *remote* collaboration the collaborators can participate from remote locations joining a shared environment. Along the time dimension, collaborative work can be conducted *synchronously*, when the participants are working at the same time, or *asynchronously* if they work at different times, like in globally distributed teams. Involving the xR dimension, the collaboration takes place within virtual environments, referred to as CVEs. In the xR dimension, *symmetric* collaboration describes a collaboration within the same reality-virtuality level, for instance in VR. On the contrary, in *asymmetric* collaboration the CVE representation can vary within the MR continuum between the collaborators. For instance, a part of the participants can be inside the AR representation of the CVE, while another part can participate within the VR one.

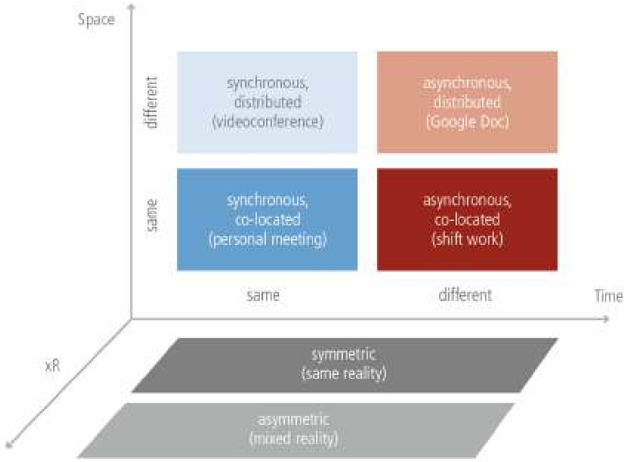

Fig. 3. CVE matrix including the possible collaboration styles within the dimensions of space, time and xR. Source: own extension of the groupware matrix from *Groupware: Computer support for business teams*, by Johansen, 1988.

2.3 Technical Implementation of CVEs

CVEs enable non co-located persons to meet in a virtual environment. They come in many varieties, from a simple chat room, an online game, to a virtual conference accessed through immersive hardware systems. This section focuses on the key aspects of CVE software, like connectivity, communication architecture, and interaction and collaboration paradigms. Furthermore, in Subsect. 4.2 hardware setups of possible projection systems are presented.

Connectivity is key to being able to connect applications over the internet. First, the applications have to be visible to each other to be able to meet up. This can be achieved in a local network by defining a system as main server. When connecting over the internet, it is in general not possible to address the systems via IP, as they are behind a Network Address Translation (NAT). In this case, it is necessary to have a match making server that can be reached from the internet. Depending on the communication architecture, the match making server can also have the role of a TURN server or even application server (TURN stays for Traversal Using Relays around NAT). A TURN server helps two peers to connect, the server then routes any data streams between the peers. An application server is required when the application uses a server-client based communication, where the server manages the application state. This is typical for online games where the server manages the application state like players, their progress, and the state of the environment.

The communication architecture is based on Representational State Transfer (REST), Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) data streams. REST is typical for communicating control messages with servers, for example for match making or session management. TCP data streams are used for important data like model data transfers, user interaction, or application events. This allows to keep track of such data and detect inconsistent states between collaborators. UDP data streams are useful when transmitting audio and video streams and maybe tracking transformations. This kind of data stream is robust, as dropping data packets will not result in corrupting the application or significantly impact the user experience, at least if there is not too much loss due to a bad connection.

The available collaboration paradigms depend on the connectivity and communication architecture. The most basic setting is to display user avatars and a chat window to communicate. This results in a very small network communication data volume, as only the transformation matrices of the users have to be synchronized between application instances. Instead of a chat, it is also possible to start a conferencing tool like Zoom or Teams, which will increase the transmitted data volume. The next step to ease the communication is to enable voice over IP, this is more challenging on a technical level as the application needs to access microphone devices and stream the data to other nodes as well as play the voice streams locally of collaborating users. Even more challenging is synchronizing the scene graph, the simpler version is to just synchronize the visibility and transformation of 3D assets, but each asset is already shipped with each copy of the application.

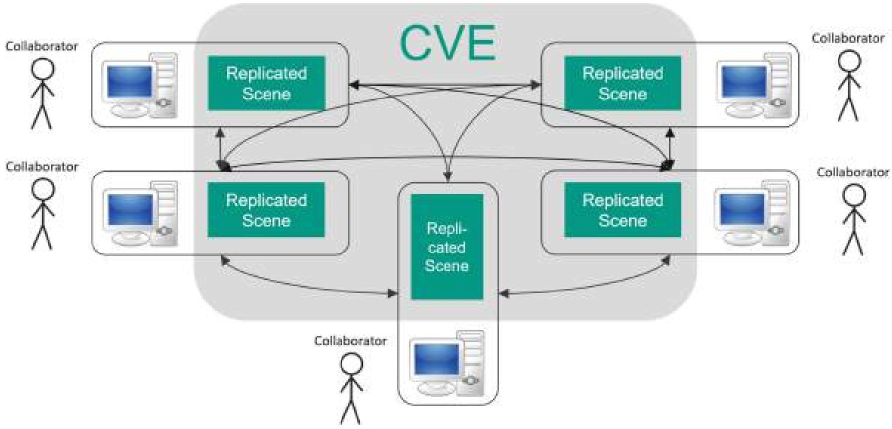

Fig. 4. A shared CVE consists of several replications of the shared 3D scene on the local systems of the users. The replicated scenes require synchronization between all systems to ensure a consistent CVE for all participants [68]. Source: own representation based on *Active transactions in collaborative virtual environments*, by Pečiva, 2007.

It is also possible to synchronize any 3D content, for example generic triangle meshes, but this requires a complex state management of the VE, per frame change lists, change filtering, serialization and deserialization, and much more [68]. Pečiva [81] presents several strategies for the replication and synchronization of VE for remote collaboration. Furthermore, the work introduces the Active Transaction (Fig. 4) as a more efficient approach for synchronous remote CVEs.

This is the basis for Collaborative Virtual Environment (CVE) applications, where users may present and discuss any 3D data (e.g., CAD models) within a shared virtual environment.

3 Significant Challenges of CVEs

3.1 Acceptance of Immersive Approaches

The effective implementation and efficiency of CVEs are intimately linked to the effects that virtual immersion and associated technologies have on users, and therefore, by extension, to their ability to accept them. Indeed, virtual immersion may place users in different psycho-physiological and behavioral states than those observed in the real world. Numerous issues are to be considered when developing CVEs and here we present three major ones of those (Fig. 5).

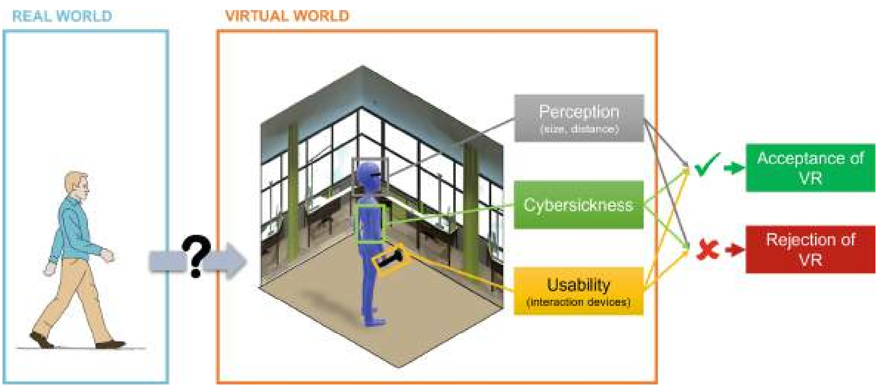

Fig. 5. Three major challenges for the acceptance of immersive approaches, here as an example in virtual navigation tasks. Source: own representation.

Cybersickness. Among the recurrent issues of immersive technologies, cybersickness is undoubtedly one of the most important but also among the most studied. It is indeed known that virtual movements, undergone or carried out by a user, cause a characteristic malaise, with symptoms close to those of motion sickness: nausea, pallor, stomach ache, fatigue, etc., which can even lead to vomiting. If the phenomenon has been abundantly described in the literature [10,49,108], its explanation is still subject to numerous studies because of its high complexity. Nevertheless, we can summarize here the main theories associated with the appearance of cybersickness, the factors that can promote it, and the means currently developed to mitigate its effects.

The main theory commonly accepted to explain the appearance of cybersickness is the sensory conflict, introduced in 1975 by Reason and Brand [89].

This theory states that the human body uses the visual, vestibular and proprioceptive systems to orient itself in space, and that a conflict between the information received by these systems leads to sickness. In virtual immersion, it is very frequent that a virtual movement stimulates the visual system but not the vestibular one because the user does not move physically or only slightly. A conflict then arises between the two systems, causing cybersickness. Another theory, also very widespread, is the ecological theory, proposed by Riccio and Stoffregen in 1991, according to which sickness comes from prolonged periods of postural instability [91], which may themselves be triggered by a dysfunction of the body's balance mechanism in the presence of visual stimuli [103]. This theory has highlighted the fact that a significant amplification of the postural sway precedes the onset of sickness [102], and several studies in virtual reality have helped to better characterize the features of postural sway in order to anticipate the occurrence of cybersickness (e.g., [12]). A third theory, called the evolutionary theory and developed by Treisman in 1977, proposes to assimilate motion stimuli to intoxication, triggering corresponding reactions by the body [109]. However, this theory is not widely accepted, as several studies have pointed out inconsistencies [38,77]. The last theory, less known, is the rest frame theory, introduced in 1998 by Prothero [86]. This theory, considered a refinement of the sensory conflict theory [85], stipulates that a person uses stationary references in space, and that when an appropriate reference cannot be chosen, for example, in the presence of motion cues, cybersickness occurs.

The levels of cybersickness experienced are highly dependent on several factors. On the one hand, as each person is different, parameters related to each person can influence how this phenomenon may be experienced. Past studies have shown, for example, that people suffering from balance organ disorders in their inner ear are insensitive to motion sickness [43,120]. Similarly, females seem to be more susceptible than males to cybersickness, due to differences in hormonal levels [33], in the field of view [57], but also in the way sickness symptoms are reported [5]. Age is also considered as a parameter that can influence sickness [20], but opinions are more divergent, as sensitivity can also be affected by life experience, particularly that in video games; a person accustomed to video games is able to develop abilities to move quickly and accurately in a virtual environment [99], which desensitizes from cybersickness [31,98]. Ethnic, genetic, and hereditary factors may also be involved in susceptibility to cybersickness [51,52]. On the other hand, parameters related to the technology itself can influence the levels of cybersickness. Among these, we can cite the type of immersive device used (e.g., Head Mounted Display (HMD) or Cave Automatic Virtual Environment (CAVE)-type system) [66], the field of view of immersive devices [26], which is usually smaller for most devices on the market than the human one, a high latency of the system [83], low frame rates [57], poorly adjusted interaction parameters [116], unsuitable interaction interfaces [70], or long-time immersion [11].

Many works have tried and continue to try to reduce the effects of cybersickness. One way is to improve existing virtual displacement techniques, by adapting navigation parameters according to the environment in the immediate vicinity [13] or by taking care not to exceed certain speed and acceleration thresholds [105,124], but also by adapting the field of view and adding blur in the peripheral vision according to the motion [14,104]. Another method is to develop new techniques of virtual displacement, including teleportation-based [72], motion-based and room-scaled-based such as redirected walking [28], or controller-based techniques [50,115]. Cybersickness can also be minimized by using motion platforms such as omnidirectional treadmills [61], which however may require space and be costly. Another solution can be to use a guiding avatar [60], representing the user in a third person perspective, as in many video games and more recently in virtual world applications (e.g., Virbela, Horizon Worlds or MeetinVR), though further studies are necessary to confirm its efficiency. More recently, work has been done to recenter interaction in virtual environments on the user, or even to individualize the interaction, with the assumption that on the one hand the level of presence in the virtual environments will increase and on the other hand the levels of cybersickness will decrease. Thus, it is possible for example to limit cybersickness by adapting virtual accelerations according to the user's physiological state [82]. Similarly, with the massive development of artificial intelligence tools, one promising perspective is to predict the onset and thus minimize the levels of cybersickness based on the users' profile [117] or behaviors and activities [44].

To summarize, cybersickness is a recurrent phenomenon to be carefully considered to prevent users from rejecting immersive technologies. It is doubtful that cybersickness will be one day eliminated. However, one should make sure to always minimize it. All parameters, including human and technological ones, should be reviewed to provide optimized immersive experiences. Minimizing latencies, carefully designing immersive scenarios, and taking users' peculiarities into consideration in the design of interactions, are among the ways to succeed.

Usability and Interaction Modalities. Another reason for the rejection of xR technologies often observed on end-users lies in the way interactions are designed. We have mentioned above that inappropriate interfaces can be one cause of the occurrence of cybersickness. In fact, it is often noticed that novice users struggle with the interfaces to achieve a task, which (i) deteriorates the user experience, and (ii) questions the usability of the xR system more generally.

Therefore, it seems crucial to optimize the usability of an xR interaction system for its better acceptance. According to the ISO 9241-11:2018 standard, the usability of a system is defined by its ability to allow users to perform tasks in an efficient, effective and satisfactory manner [45]. Thus, in xR, the question is how to interact with a virtual environment fulfilling these criteria?

Intuitively, it can be thought that the interaction allowing the greatest usability is natural interaction. Indeed, this type of interaction requires devices that are generally non-intrusive for the user, such as a microphone or a camera, and exploits skills acquired at an early age, such as walking, talking and gesticulating. However, the integration of such interactions in xR cannot be achieved without constraints. In VR, the particularity, as seen above, is to be immersed in a virtual environment and for that, it is necessary to use devices such as HMD or screens of more or less size. However, these devices and the systems necessary to operate them impose physical constraints in an inherent way, e.g., limited tracking space, limited physical movement space due to the presence of screens. Thus, to navigate in a virtual environment for example, if it is larger than the physical space, navigation techniques and devices must be employed, as natural walking becomes very quickly constrained. We have seen above several categories of existing navigation techniques. A technique that has attracted the VR community's attention for a few years is redirected walking [28]. Its principle is to make users believe that they are walking in a straight line in the virtual environment while physically they are walking in a curve so that they remain in a constrained physical space. If the undeniable advantage of this technique is to allow users to walk in a natural way, it nevertheless requires a fine-tuning of the redirection parameters which, if improperly done, can make the experience unsatisfactory and thus the system unusable [56]. Gesture and speech interaction suffers from problems related to gesture and speech recognition, which assumes on the one hand that the system has a pre-recorded or learned knowledge base and on the other hand an accuracy and recognition rate acceptable to the user. On this last point, recent works show increasingly high recognition rates (e.g., [122]) but which do not yet reach 100% or do not allow an optimal usability [1]. This, in turn, can affect cognitive load [30]. Therefore, even though natural interaction seems at first glance seducing, there are still avenues for research to get natural interaction effective, efficient and satisfactory to realize tasks in xR.

The same thought goes for computer-based interaction, involving interaction devices, such as controllers or joysticks, but also interaction techniques. Several studies investigated the usability of immersive interactions (e.g., [55,69]) and how cognitive load can affect user experience (e.g., [123]). Overall, the simpler the interaction, the better [69]. Practically, that means also that when operating an immersive application, the fewer explanations are needed to use the system, the better. A last point is to ensure that interaction parameters (i.e., navigation speed, acceleration) are well tuned to maximize chances of usability. For instance, George et al. proposed a navigation method in virtual environments consisting in scrolling on a smartphone as on webpages [32]. Although smartphones are commonly used, the navigation parameters were not tuned properly, preventing users from navigating smoothly and therefore degrading user experience.

A last aspect to consider in interaction relates to multi-modality. Here, multi-modality consists in soliciting other senses than vision. It is well known now that integrating, for instance tactile or haptic feedback is of major importance for enhanced user experience [21,119,121]. A huge literature exists on prototypes of devices allowing tactile and haptic feedback (e.g., [16,58,79]). There have been companies selling haptic gloves and arms for more than 25 years, however they were released at a time when VR was not affordable and still in its infancy. Recently, thanks to miniaturization, lower component costs, and the increasingly widespread of xR technologies, several startups and companies have released new various and more affordable haptic systems, including gloves and suits, to provide tactile, haptic, even thermohaptic feedback, such as Manus[3], HaptX[4], WEART[5], or Actronika[6]. Aside from haptic feedback, stimulating the vestibular system is another way to improve user experience and contribute in reducing cybersickness effects. Sensory stimulation can be made through motion systems, as massively performed in driving simulation, where multiple degree-of-freedom platforms are used to render realistic vehicle motion with appropriate motion cueing algorithms [49]. Such systems can be used in various use cases, such as training in hazardous situations [21]. Other sensory cues, such as auditory or olfactory, can be integrated to further immerse users.

To summarize, the acceptance of xR technologies is dependent on how well they fit users' needs and experiences. As efficiency in work is always sought, immersive applications should be designed in a way to ensure maximal usability. The simpler, the better. Integrating multisensory feedback provides added value to user experience, however it is not a question of combining a maximum of technologies if the use case considered does not require it, at the risk of producing the opposite effect of that sought. Let us imagine for example an immersive training situation in maintenance involving the closing of valves. If the main objective is to learn the maintenance procedure rather than the way to close valves, there is no need to ask operators to do the gesture of closing accurately, nor to include haptic feedback; just virtually touching the valve and pressing a button on the VR controller to trigger automatic closing is sufficient. Therefore, when designing an immersive application, it is of primary importance to build its specifications properly to derive the right choice of technologies.

Perception of Virtual Environments. Another aspect to be considered is to ensure that end-users perceive virtual environments correctly. Typically, past work has largely reported misperception of distances and scales in VR, with observations revealing underestimations of distances up to 50% compared to reality [90], and virtual objects appearing smaller than in reality [101]. Such effects may disturb end-users in tasks, such as product design reviews or navigation in wide environments, in which size or distance checks may be required. In fact, such inconvenience may lead to a loss of presence in the virtual environment [41]. Reasons are not yet fully understood and are still the object of intense research. Though, it is known that a mix of factors may affect perception. For instance, the weight of a head-mounted display may influence distance perception above three meters [19]. Graphics quality is often cited as an impacting factor, including for example avatar realism [76], though some research does not consider it as significant [107]. More important is the way virtual cameras are set with respect to users. The inter-pupillary distance for instance should be tuned accurately in immersive systems (both physically of the devices and

[3] https://www.manus-meta.com/.
[4] https://haptx.com/.
[5] https://www.weart.it/.
[6] https://www.actronika.com/.

by software) to each user [118], which may not always be easy, as some head-mounted displays for example do not offer the possibility to tune this distance outside a pre-defined range. Lenses present in HMDs may also bring distortion of the displayed images. Other parameters from the display can also be considered, such as resolution, contrast, brightness or refresh rates [106]. Distances of users and virtual objects to the screen [7,64], or the cognitive profiles of end-users [6] are other factors known to impact distance perception.

To remedy misperception in virtual environments, past studies revealed that performing actions, such as navigating in the virtual environment or manipulating virtual objects, may positively affect distance perception [113], within low-to-medium-range distances (usually less than 100 m) [39]. Furthermore, a correct setting of immersive devices and VR software is necessary. Simple checks can be performed to verify that the parameters of immersive systems are correctly set up [96], including checking the inter-pupillary distance to fit each user, verifying the users' eye location in both horizontal and vertical directions, checking the proportions and sizes of virtual objects in screen distance, or verifying that size changes correctly with varying distance.

3.2 Continuous Collaboration Throughout Different Dimensions

One of the open issues in the research of immersive collaborative environments is to enable switching between different collaboration modes and representations, for instance the change from co-local synchronous collaboration in AR to remote asynchronous collaboration in VR [27]. To enable more flexibility in collaborative work, CVEs should enable a transition between the different collaboration modes within the space, time and xR dimensions (Fig. 3).

Space Dimension. In the space dimension, the CVE should support transitions between co-local and remote collaboration. At the current state, collaborative work takes place either remotely, like in video conferencing, or co-locally, like in personal meetings. In xR CVEs are possible which will allow the participants to transit seamlessly between these two modes [27] allowing more mobility during collaboration while keeping the natural communication form.

For instance, collaborators who are running late for a meeting can virtually join while being on their way to the meeting location. With MR technology the virtual avatars of the remote collaborators are projected into the meeting environment similar as in Fig. 2. The representation of the users within the 3D meeting environment is enabled by immersive technologies. As a virtual representation of the remote participants, 3D avatars enable a natural communication between the present and distant collaborators, including verbal speech and non-verbal cues like gestures, gaze, and facial expressions. Compared to video calls, immersive CVEs improve collaboration by including spatial information. For instance, immersive CVEs allow the communication of deictic gestures and gaze directions, which is not possible in traditional video calls but play an important role during face-to-face communication. As soon as the remote collaborator arrives at the meeting location, the CVE system is responsible for switching the collaboration mode from remote to co-located. In particular, the avatars and digital speech transmission must be disabled for all co-located participants and enabled for the remote participants.

Time Dimension. In the dimension of time, the recommendation is to provide possibilities to switch between synchronous and asynchronous collaboration modes [27]. Synchronous collaboration in immersive CVEs is a well-studied subject [3,27] and many companies already offer services and software products [112] which can be used within distributed teams as a shared CVE. Unfortunately, that is not the case for asynchronous collaboration in immersive CVEs [3,18,27,42]. Reviews on MR collaboration highlight the benefits asynchronous collaboration methods can bring to different application areas and emphasize that future CVEs should offer possibilities for both, synchronous as well as asynchronous collaboration [3,27].

Before exploring the transition between synchronous and asynchronous collaboration, more research is needed for understanding and defining concepts for asynchronous work in immersive environments.

In asynchronous collaboration, the participants do not have to be present at the same time within the collaborative environment to be able to conduct collaborative work together. In other words, the collaboration takes place over an extended time duration [42]. The collaborators can progress on their tasks independently within the CVE which will track and merge their changes to ensure a consistent state of the work for all participants.

The majority of the works show concepts for leaving annotations in the virtual space for information exchange between the collaborators, but asynchronous collaboration in immersive CVEs can go far beyond the scribbling of static virtual content and its consumption at a later time [42]. Unlike with static annotations, dynamic behaviors and actions can be preserved within the collaborative space and be presented on demand for later consumption. In fact, the work on a shared task can be visualized within the working space by 3D avatars of the previously working collaborators without them having to participate at the same time.

A concept for conducting manual work asynchronously in VR is presented in [67]. The collaboration is considered to take place between an expert on a specific assembly task and a trainee who is being asynchronously instructed by the expert, as depicted in Fig. 6. In the presented concept, the movements and actions of the collaborators are recorded by the VR system while they are working on the assembly task. To instruct the trainee, the expert can capture his actions within the 3D space and send the record file to his trainee. The trainee can proceed with the training instructions at any time. Therefore, the received recording can be replayed within the CVE, allowing the trainee to see a *ghost* of his trainer showing the assembly steps including the ghosts of the involved assembly parts. The *ghost* visualization has been chosen to distinguish non-present collaborators and objects from present ones. During the replay of

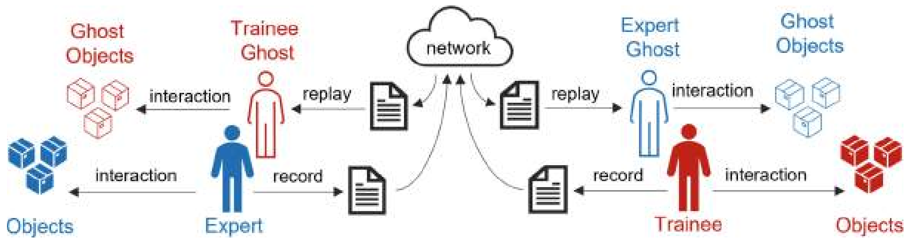

Fig. 6. Concept for asynchronous remote collaboration between two users. Source: own representation from *Asynchronous manual work in mixed reality remote collaboration*, Mayer et al., 2022.

the *ghost* trainer, the trainee can work with the present objects, imitating the assembly process. Additionally, the actions of the trainee can be recorded by the CVE and sent back to the trainer for evaluation and if needed corrections.

This concept, including the immersive capture and replay of the collaborators' actions and the interaction with their results, enables collaborative work on spatial tasks even if participants are not available at the same time. Besides training scenarios, the concept can be applied to the documentation of cooperative work, team performance reviews, remote maintenance, co-design and many more.

xR Dimension. Regarding the xR dimension, CVEs should enable switching between different representations during the collaboration. For instance, the collaboration can begin in AR for the co-present collaborators and continue in VR when they switch to remote collaboration. Despite the change, the collaborative experience should remain consistent for all participants. Figure 7 shows first tests on asynchronous remote collaboration between a VR and an AR user [67]. Therefore, the CVE as well as the exchanged data between the collaborators must be compatible regardless of the xR device (whether VR or AR).

Depending on the xR device, the visualization of the remote collaborators and the tracking of the local user may vary. Regarding the representation of the user's hands, most VR devices allow the usage of hand controllers for input, while the majority of AR devices rely on hand tracking. Therefore, in VR only the movements and actions of the controllers are tracked and need to be mapped to a virtual hand representation (Fig. 7 left). Meanwhile, with hand tracking in AR the hands are recognized by the AR system tracking the hand joints which can be used to animate the virtual hands (Fig. 7 right). As a result, the CVE has to support several hand representation and tracking techniques and handle the mapping of the different hand models.

Furthermore, VR requires virtual objects to interact with, while AR allows the interaction with physical objects. Within the remote maintenance scenario, a remote expert could explain maintenance steps on a virtual representation of the physical objects to an on-site worker trying to reproduce the steps on the

Fig. 7. MR collaboration between two users on an assembly task [67]. Right: VR environment with virtual hands replacing the controllers. Left: AR environment including hand tracking and virtual assembly parts which will be mapped to the physical parts. Source: own representation from *Asynchronous manual work in mixed reality remote collaboration*, Mayer et al. 2022.

physical objects. This scenario requires the localization of the physical objects within the on-site working environment. Once localized, the physical objects can be overlaid with virtual holograms of the remote expert. On the expert side, a virtual representation of the physical objects is needed to create the guiding instructions, which can be obtained for instance from CAD data.

3.3 Measuring the Usability of CVEs

To measure the usability of a system, three metrics are proposed in the ISO 9241-210:2010 standard: efficiency, effectivity, and satisfaction. For each of the metrics, different tools can be utilized to elicit quantitative or qualitative measurements. For instance, effectiveness can be measured by analyzing the completeness or correctness of a task performed within the CVE, efficiency by measuring the required time to complete the task and the satisfaction via user feedback in a questionnaire (i.e., System Usability Scale (SUS) questionnaire).

Quantitative data is usually measured via sensor feedback, while qualitative data can be sampled from user questionnaires and is therefore hard to compare between the study subjects. Nevertheless, qualitative results can be used to clarify and explain the quantitative results.

Physiological sensor measurements can be used to evaluate the user experience of CVEs using non-invasive data collection methods such as eye tracking, electrodermal activity, or heart rate [47,62]. Physiological signals provide valid and often unique data that is of particular interest to the user experience. Physiological measurements can provide deep insights into effects such as immersion and presence. They can quantitatively and objectively measure users' subjective experience while interacting with the virtual world [47]. Unlike self-assessment or low-scoring questionnaires used during or after immersive activity, physiological measures can be used to collect user data at the precise moment when users are engaged, immersed, or in flow without interrupting the user experience. For the studies with collaborative environments, a large sample (more than 30 users per test group) should be used because the fidelity, and therefore the complexity, of physiological measurements is much higher. To measure the study variables, methods with different levels of fidelity should be used. Such methods include tracking variables to map different motivational states (between traditional and immersive collaboration sessions), embedded surveys to measure usability, physiological signals such as heart rate, electrodermal activity to measure presence using near-infrared spectroscopy (NIRS), and other non-invasive methods. Results can be presented as inferential statistics and calculated using quantitative methods such as multivariate analysis of variance (MANOVA). In this way, it is possible to verify whether there are statistically significant effects on specific variables compared to other collaborative instruments.

4 CVE Application Areas

The application areas for CVEs are manyfold [3] since collaboration is essential in every domain and many areas benefit from immersive technologies. In the following, business, engineering, and education application areas are presented.

4.1 Business

In the business application area, CVEs are mostly utilized to have face-to-face meetings despite working from remote locations as depicted in Fig. 2. This is enabled by immersive CVEs providing a 3D meeting environment as well as personalized 3D avatars representing the participants. As in physical co-located meetings, communication cues like facial expressions, deictic gestures, and gaze directions are important to have an efficient discussion and have to be visualized during the collaboration. Furthermore, the CVE should contain common meeting tools, such as whiteboards, post-its, and markers and allow intuitive interactions with the virtual objects as discussed in Subsect. 3.1.

For business meetings, the support of other multimedia sources inside the CVE is important. Usually, meetings involve the usage of digital documents, websites, 2D assets like images and videos as well as 3D assets like 3D models. Another significant requirement in this area is the support of massive collaboration. CVE meetings can involve small teams with up to ten participants, but also hundreds of participants, for instance during virtual exhibitions and conferences.

Within the business area, CVEs can furthermore be used for collaborative data analytics and decision-making, utilizing the third dimension immersive interaction to get a better overview of the massive data sets.

Finally, for marketing and procurement purposes, CVEs enable to approach customers remotely and directly in their homes and institutions. Virtual previews of physical products can be customized and experienced in an immersive space, allowing a better idea of how the product will finally look like and behave. With the use of AR the virtual products can even be placed inside the own homes[7] or on our own bodies[8].

4.2 Engineering

An application domain in which collaborative work is fully integrated is engineering, in particular Product Lifecycle Management (PLM), and more recently in the construction field with the Building Information Modeling (BIM) process. The PLM cycle, specific to each product or service developed, involves several stages, among which design, manufacturing, marketing, maintenance, and recycling. During these different stages, collaborative sessions can take place between collaborators according to the modalities explained in Subsect. 2.2. These collaborators can come from different fields but all work in parallel on the same virtual support, a digital mock-up (DMU), integrating the data from all fields, and thus carry out concurrent engineering [111]. With BIM, it is even more challenging as mock-ups should continuously be updated, not only during construction and until the delivery of the buildings, but also during usage, to facilitate management for maintenance or update operations, with the consideration that a majority of stakeholders (e.g., some craftsmen) may have not adopted computer-supported tools [87].

Virtual and augmented reality has emerged as an indispensable technology that facilitates system development while reducing development time and costs, but also increasing user safety in hazardous situations[9]. The literature is rich in propositions of system development methods, collaborative or not, using virtual reality (e.g., [17,29,63]). Virtual reality allows, for example, the visualization at real scale of the digital mock-up and interaction in a natural way (e.g., turning around the mock-up, selecting components, simulating components assembly). In concurrent engineering, it is possible to imagine each collaborator using his/her own immersive visualization device (i.e., a CAVE-type system, an immersive headset, a powerwall), visualizing the representation specific to his/her field of the same digital mock-up, and exchanging on modifications to be made or the validation of the mock-up. Thus, for example, for the design of a vehicle interior in an immersive environment, a designer and an ergonomist can work together at the same time, the first one being in the position of the customer in the virtual vehicle, the second one taking a step back from the vehicle to measure and validate the ergonomics. In a co-located synchronous collaborative environment, the use of powerwall or CAVE-type systems is interesting compared to immersive headsets. Indeed, these systems allow collaborators to exchange while physically seeing each other, thus without the need to represent the others virtually, unlike immersive headsets, which shield from the real world (Fig. 8). However, the co-located simultaneous display of a digital mock-up in different representations is

[7] IKEA Place: https://www.homeandsmart.de/ikea-place-app-how-to.

[8] FXMIRROR: http://www.fxgear.net/vr-fashion.

[9] Capgemini, Augmented and Virtual Reality in Operations: A guide for investment: https://www.capgemini.com/us-en/augmented-and-virtual-reality-in-operations/.

only possible if the projection systems have the capacity, which is still rarely the case, for reasons of cost and complexity of implementation. For this purpose, several solutions exist:

Fig. 8. Manufacturing planning in a CAVE system: the left person is presenting the layout from her viewpoint, while having a discussion with the right person who is viewing the same layout. Source: photography by Jan Siebel.

- Use high-frequency projectors: to allow an optimal immersive experience with active stereoscopy systems (using shutter glasses), it is necessary to display images at a refresh rate of 60 Hz per eye. With two collaborators, video projectors capable of displaying images at 240 Hz are required. The number of collaborators can then be quickly limited, though some video projectors allow going up to 360 Hz[10]. An alternative is to use multiple 120 Hz projectors [59], however the complexity of installation increases.
- Use autostereoscopic projection devices: these devices, which do not require wearing glasses, are based mainly on lenticular networks or parallax barriers [2,22]. However, they do not allow movements in all directions.
- Mix active and passive technologies: the projection can be by default in passive stereoscopy (using polarized or anaglyph glasses), but the separation of the views is done in an active way, for example by software [65].
- Use active stereoscopic projection in degraded mode: a stereoscopic image is divided into two monoscopic images, each representing a viewpoint of each user, as done for example in Arts et Métiers Institute of Technology's CAVE in France. However, this solution only works with two users and suppresses depth perception.

Other possibilities include asymmetric setups, i.e., different devices used in the same session, for example, a VR device and an AR device, or an immersive device

[10] Digital Projection INSIGHT 4K HFR 360, https://www.digitalprojection.com/emea/dp-projectors/insight-4k-hfr-360.

and a control screen, which is particularly suitable to train operators for instance (see also Subsect. 4.3 and Fig. 9). In such a situation, the trainer not only sees the actions of the trainee in the virtual environment, but can also trigger events or scenarios thanks to a dedicated interface.

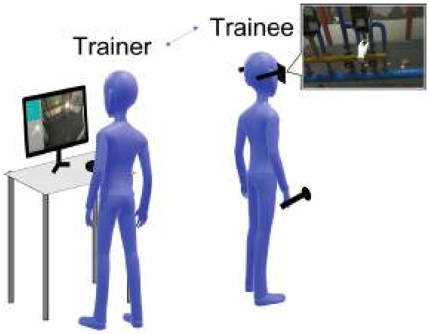

Fig. 9. Example of collaborative setup for training involving a trainer and a trainee. Source: own representation.

In the maintenance field, collaboration using immersive technologies has proven to be effective [8,110]. The main point is collaboration between distant people, synchronously or asynchronously: an operator stands in front of a machine to be maintained wearing augmented or mixed reality glasses, or holding a tablet PC, and shares his/her environment with an expert located in a distant office who provides guidance through voice and augmented indications sent on the operator's glasses or tablet. The key issue is to define the right amount of indications to display to the operator and the suitable interaction methods not to lead to cognitive overload [93].

One important aspect to consider when developing collaborative engineering in virtual environments relates to the management of data. Since each field generates its own model and representation using domain-specific tools, interoperability shall be provided to ensure data are correctly synchronized and integrated into the collaborative digital mock-up [4], and usable in immersive environments.

4.3 Education

Immersive collaborative environments have great potential for learning and teaching use cases. They can be used not only for acquiring knowledge for a particular domain and enhancing motor-coordination and physical skills, but can also improve communication, collaboration, soft skills, and many more [34]. Further benefits of immersive teaching and learning (depending on the use case) may be the increment of motivation and concentration, saving of time and costs as well as higher safety and health protection, when the real environment is too dangerous [36]. Regarding the learning goals, technology setup, and implemented features, there are many ways to manifest those benefits. An early study showed that the immersive 3D learning environment helped participants feel part of a group and that the environment was an effective way to foster social interaction and group dynamics [73]. Communicating while in an immersive learning environment enables educational methodologies such as situated learning and peer/pair learning. Soft skills that are trained in CVEs are teamwork, problem-solving, decision-making, management, leadership competencies, and others. The networked virtual environment emulates the kind of collaboration, that is usual for the real world and can benefit collaborative and active learning [15]. An example for a multi-user VR environment is the vocational training for anaphylactic shock, which enables the critical paramedical cases, which happen too rarely, to be trained in a safe collaborative environment [94]. The industrial training, provided as an example by Sobota et al. [100], shows that using a CVE can deliver a practical training without the need to allocate real workspace or even instructors, which leads to saving many resources.

From a technical perspective, an educational setup can use powerwalls or CAVE systems, where a group of learners with or without a teacher can observe, interact and discuss the projected virtual environment. Learners can collaborate co-located in a team, in order to solve a specific task, discover mistakes, solve a problem or make decisions together. For example, the MIT Media Lab presents a collaborative co-located environment called Electrostatic Playground, where learners can explore and discover principles of electrostatics through experimentation [35]. Furthermore, the asymmetric collaboration between CAVE and VR or AR headsets in remote locations can also be applied efficiently to learning [24,84].

Immersive environments can also provide a good communication platform for learning a foreign language, especially between students from different countries and cultures. In the context of communication, the use of VR can overcome language barriers [80]. If trainees do not understand the information verbally, an immersive environment provides a visual representation. Furthermore, the learning environment can be supported by automatic real-time translation algorithms to enhance the collaboration.

While collaborative virtual environments for educational purposes have numerous benefits, there are also some risks to be considered, such as safety (risks of mental health issues due to prolonged exposure to VR or heavy headsets used by young children) or cybersecurity (risks of not permitted access to personal information and biometric data from third parties). Nevertheless, researchers are working to address these limitations, and we will see more and more widespread use of CVE applications in the education area in the future.

5 Summary and Outlook for Global Digital Work

Innovations coming from global high-tech companies, research, the entertainment, and gaming industry are constantly advancing the further development and spread of CVEs.

Global companies are developing technology for remote collaboration and recently focusing on immersive CVE devices and software. Furthermore, they are working on collaborative platforms, for instance Meta's Metaverse[11], Microsoft Mesh[12] and NVIDIA's Omniverse[13], and starting education programs, like the "Metaverse Academy"[14] to prepare next-generation users and developers for the new era of CVEs. There is an observable competition between the global tech companies trying to establish their technology as the mainstream CVE platform.

Innovations from the entertainment and gaming industry are constantly pushing the requirements for the research and development of CVEs by raising the standards for visualization, human-computer interaction, and the scalability of remote multi-user applications [37]. The success of games has the power to raise technologies from a niche into the mainstream (mass-acceptance) and on the other hand, a technology can get completely rejected by the users, if there are not enough successful applications as it was the case for the Windows Phone[15].

In research, new knowledge is continuously generated for the development of new hardware, software and interaction approaches. The broad upcoming of immersive technologies opens opportunities for new tasks to be performed remotely, which were yet not possible with traditional tools. Immersive technologies are very interesting for tasks involving spatial information, for instance collaborative engineering. However, they also involve many issues to be solved for a broader acceptance, like the effect of cybersickness or usability. Research does not just provide answers on how to implement innovative CVEs, but also how to apply them in the different work domains [27,114]. Finally, the increased distribution of the workforce [9] as well as the increasing demand for more flexibility regarding the workplace and hours [25] are social drivers of CVE development.

On the other hand, remote collaboration in virtual environments is facing various challenges. As previously mentioned, collaborative work involves collaborators who are working together on a task, as well as the work environment where the collaborative task is performed. Therefore, the design of successful CVEs involves challenges that are affected by the changes in social and environmental requirements for collaborative work. The recent environmental challenges are mainly affected by globalization and climate change. Since globalization involves highly distributed stakeholders, opportunities for spontaneous physical meetings are reduced [53]. Additionally, frequent traveling is discouraged to minimize carbon footprint, resulting in a need for CVEs to enable team work from any geographical location at any time and provide tools to process the collaborative tasks.

From the social perspective, the main challenges are home-office work and the acceptance of CVEs and the involved technology. For employees, a new set

11 https://about.facebook.com/.
12 https://www.microsoft.com/en-us/mesh.
13 https://www.nvidia.com/en-us/omniverse/.
14 https://www.metaverse-academy.ch/.
15 How Microsoft Blew It With Windows Mobile:
https://www.wired.com/2009/11/microsoft-windows-mobile/.

of skills is prioritized, for instance self-management and independent working, while managers have to restructure the work processes and provide training to prepare their staff for remote work. The limited ability to measure the financial results of digital endeavors makes it hard to justify the use of CVEs [53].

Besides the obvious occasions when remote CVEs are a necessity, for instance during lockdowns, there are also benefits for remote work in general, as listed in [53]. First, digital meetings have a consistent structured character since they have to be clearly scheduled with the participants along with an agenda. When working from home, long travel times are omitted which has a positive effect on the attendance of meetings. Further, work from home-office can result in more productivity since distractions from the usual workplace are mitigated. With the utilization of recordings of the collaboration sessions, the generated knowledge remains available after the meetings and can be accessed at any time (asynchronous collaboration). The generated data during digital work can be utilized for analytics of the work processes. Finally, the extensive use of CVE technology in remote work reduces the learning curve thresholds for an effective technology utilization.

Nevertheless, there are several negative effects resulting from remote work as identified in [53] which need to be addressed. First, the less socially connected interactions between the remote collaborators can entail a loss of empathy, feelings of disconnection, and a lower morale. The transfer of tacit knowledge which requires detailed physical interaction to improve observation, demeanor, as well as subconscious elements is strongly limited to impossible in traditional CVEs. Finally, a tendency for longer working hours was observed when working from home [25] which combined with an intense digital environment can lead to burnout [53].

From a pure research and technological perspective for immersive technologies, global digital work opens large avenues to explore [114], including realistic and dexterous multimodal collaborative interaction [18,27], multiscale collaboration [27], cloud-based or robot-powered collaboration, co-presence and social presence [75], or ethics of xR[16].

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Participation in Work of People with Disabilities by Means of Technical Assistance

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Abstract. The comprehensive realization of social participation for all individuals is a particular challenge in which the working world proves to be an important sphere. Despite normative reference points through socio-political innovations, people with intellectual disabilities and a high need for support are particularly excluded. Even in sheltered workshops, this group of people is excluded from participating in work as the challenges of life and labor in the 21st century are becoming ever more complex and the demands of production and business stricter. As a result, people with intellectual disabilities and a high need for support often fall off the radar in current inclusion efforts and – despite legal obligations – do not receive adequate support to participate in work. To counteract the negligence and tacit acceptance of the deprivation of a large part of the sheltered workshop employees – in the sense of social affiliation by work participation – design options for promoting work participation require careful consideration. This paper analyses the use and impact of technical assistance to promote work participation for people with intellectual disabilities and high support needs and reports the results of a field study on the use of technical assistance in a sheltered workshop.

Keywords: Professional participation · People with disabilities · Technical assistance · Inclusion · Participatory justice

1 Participation in Working Life of People with Disabilities

1.1 Introduction

This chapter analyzes the use and impact of technical assistance to promote professional participation for people with intellectual disabilities and high needs for support. Ensuring fair participation for all social groups is a universally recognized political, legal, and ethical goal. All members of society must be able to see themselves as free and equal, not as excluded or superfluous. Enabling everyone to participate in working life on an equal and dignified basis is an important dimension thereof. Every person of working age should be able to earn their living through work of their own choosing. Participation in the world of work is essential to be considered a full member of society. That is, nobody should be permanently excluded from working life. Therefore, initiating steps

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towards an inclusive working world is crucial so that each person can live a good and prosperous life at their own responsibility.

However, people with intellectual disabilities and a high need for support are mainly excluded from the labor market. As the challenges of life and labor in the 21st century are becoming ever more complex and the demands of production and business stricter, even in sheltered workshops, this group of people is excluded from working life. As a result, people with intellectual disabilities and a high need for support often fall off the radar in current inclusion efforts and – in spite of legal obligations – do not receive adequate support for professional participation.

Against this background, this article examines inclusion mechanisms and obstacles in the world of work. In a *first* step, we shed light on the socio-political background of professional participation. In a *second* step, the heterogeneous group of impaired and disabled employees will be defined in more detail. *Thirdly*, individual dimensions of professional participation will be explored and different ways of inclusion will be presented. We propose, *finally*, that new technologies at the workplace provide opportunities for people with disabilities to participate in working life. Supporting people with disabilities and special needs through technical assistance in the workplace enables them to carry out demanding work steps independently without being constantly overtaxed with typical symptoms such as mental fatigue, stress, and dissatisfaction. Thus, using technical assistance at the workplace ensures the usefulness of work performance and enables permanent participation in working life. Numerous research focuses on the transition of people with disabilities into the general labor market but not yet on practical implementation using modern technologies from the user's perspective.

1.2 Situation Analysis and Socio-political Background: The Necessity for Regular and Sheltered Workplaces

A declared political goal of the Federal Republic of Germany (FRG) is to ensure full participation in society for the entire population. One important subject of equal participation is the world of work (cf. Heine 2005; Frehe 2005; Keupp et al. 2008; Buchmann 2017; Blesinger 2018; Behrendt 2018). As Article 27 of the United Nations Convention on the Rights of Persons with Disabilities (CRPD), which has been valid legislation in Germany since 2009, states: "States Parties recognize the right of persons with disabilities to work, on an equal basis with others" (UN 2006, art. 27, para. 1). However, a system of vocational rehabilitation, including facilities of sheltered workshops for people who are classified as "fully incapacitated for work", existed in Germany long before. As they offer an environment for participation in working life to all those people with disabilities who cannot (yet) be (re)employed in the general labor market without special support, sheltered workshops are an exceedingly significant institution to ensure social participation (SGB[1] IX, §136, para. 1, sentence 2).

It should be noted that the CRPD obligates the States Parties to take appropriate measures to guarantee all the rights of persons with disabilities set out in the agreement, including the right to work (art. 27), as mentioned above. Supranational rules also

[1] The Social Security Code provides the legal basis for the social systems, for child and youth welfare or the rehabilitation and participation of people with disabilities.

require national implementation and application, which is achieved in Germany through a corresponding federal law. As a result, the Convention as an intergovernmental body of rules and regulations – a complex of norms under international law – has acquired the rank of federal laws. Thus, it does not take precedence over federal German social law, instead both stand on an equal footing. Buchmann (2018) critically points out that it is still unclear "who checks the implementation of these normative requirements and under what conditions and gives them assertiveness" (ibid., p. 1, own trans.).

Since the CRPD came into force, a clear upheaval and a paradigm shift can be observed in the German rehabilitation system for people with disabilities, especially for employees working in sheltered workshops. The everyday political vision and guidelines for inclusion seem to find expression in the organizational policy objective of promoting people with disabilities so that they can switch to jobs subject to social insurance contributions in the general labor market. The latter is almost unreservedly considered the sole rehabilitation goal that guarantees the highest degree of normality and self-determination. The services provided by sheltered workshops are thus evaluated based on whether the efforts of these rehabilitation facilities lead to inclusion in the general labor market (cf. Detmar et al. 2008; Weber 2012).

However, from a differentiated view, it is apparent that framework conditions for possible participation in the general labor market are lacking, especially for the group of people with intellectual disabilities and high support needs. Barriers caused by normative, economic, and structural obstacles impede their participation in an increasingly competitive, i.e., exclusive labor market (cf. Weber 2009; Wansing 2012; Kubek 2012; Weber 2012).

Against the background of the current challenges of the 21st-century living and working world, industrial companies and sheltered workshops face increasing demands on the production side. Mainly due to their increasingly frequent function as suppliers and the associated production strategies, the requirements regarding the performance of sheltered workshops, and thus the self-image of these companies, are continually changing (cf. Bächler 2017). In addition, complex products require increasingly better qualified and "more efficient" employees – again in both regular companies and sheltered workshops (cf. Reinhart and Zäh 2014).

However for most employees with a high need for support, the legally defined mandate to participate in these work activities under current conditions cannot be guaranteed. Thus, sheltered workshops can be regarded as "nursing facilities without any integration or participation perspective" (Gröschke 2011, p. 189, own trans.) for this group. Due to societal transformation processes, employees with a high need for support do not have sufficient space within the sheltered workshops to develop and unfold their potential. As a result, they are denied the opportunity to participate in working life.

Thus, it is important to develop measures that enable this group's participation in working life – also within sheltered workshops. Accordingly, Lisop and Huisinga (2004) raise the question: "Are there ways, not against, but with the new technologies, to increase autonomy, creativity, professional competence, and social commitment in thinking, feeling, wanting and action?" (ibid., p. 10, own trans.). We claim that successful participation in working life cannot be measured only by a transition to the general labor market. Rather, it must also be pursued *within* sheltered workshops for people with disabilities to counteract disregard of the deprivation and to gain acceptance of the majority of sheltered workshop employees.

In the following part, we will show how new technologies provide helpful support for professional participation for the group of people with intellectual disabilities and a high need for support (cf. Bächler 2017; Behrendt 2018).

1.3 Who is Affected: It All Depends on the Context

Advanced age, disabilities, and health restrictions significantly increase the risk of exclusion from the world of work. However, as Mathilde Niehaus has argued persuasively, focusing too strictly on legal categories can sometimes be confusing because people with a formally ascribed disability status do not necessarily have to be unable to perform their tasks. On the other hand, however, there are also cases in which a health restriction or impairment significantly reduces work activity without the employees being recognized as severely disabled by law (Niehaus 2005, p. 75). The actual number of people affected is therefore difficult to estimate.

However, it is helpful to distinguish between "impairment", which indicates the loss of a body function, and "disability", which refers to something that cannot be done in one's environment as a result of an impairment. Because the correct attribution depends on the formal criterion of functional ability, this view expresses a functionalist understanding of disability and illness. Since functional capability is, in turn, seen as the result of multiple interrelations between the person with an impairment and their environmental and personal factors, the term "bio-psycho-social model" has become established interdisciplinary (cf. Hollenweger 2003).

An internationally influential classification based on this bio-psycho-social perspective is the "International Classification of Functioning" (ICF), developed by the World Health Organization (WHO) in 2001. The ICF was first published in 1980 as the "International Classification of Impairments, Disabilities, and Handicaps" (ICIDH), amended in 1999 to ICIDH2, and extensively revised in 2001 by a large committee of international experts. This most recent understanding of illness and disability, which the WHO is now developing, focuses on the affected individual and their opportunities to participate in given social positions and goods (cf. WHO 2001).

By adopting the distinctions of this model, it is possible to consider both intrinsic and relational aspects: a person's permanent absence of a body function is a stable characteristic. However, this biological fact does not necessarily imply a disability. From a functionalist point of view, it depends on what can or cannot be done with an impairment in concrete circumstances – that is, on the interaction of the actor with a more or less accommodating social and material environment. Thus, persons with the same physical, mental or emotional impairments can be considered disabled or not depending on the specific context. Consequently, the decisive factor is whether an impairment of functional ability is present or whether effective participation can be realized despite it. Typically, people are therefore not *either* disabled *or* not disabled, but only to a *greater* or *lesser* extent and in more or fewer circumstances. The same can be said according to the salutogenic model for the related phenomena of health and illness, according to which "all people are to be regarded as more or less healthy and at the same time more or less ill" (Bengel et al.1998, p. 24; own trans.).

In the context of the world of work, we are dealing with a very heterogeneous group of people with the most varied forms of health impairments and resulting disabilities, which can hardly be adequately quantified. Rather than speaking in general terms of employees with health impairments and disabilities, following Klaus Wieland (1995), we would like to describe persons who have health impairments that are significant for their previous work activities and with whom it is no longer possible to carry out this work without restriction as "performance converted". Accordingly, inclusion efforts must not only be aimed at employees with legally recognized disability status but must also include the group of performance-converted employees (cf. Niehaus 2005, pp. 73–75).

2 Participatory Justice: Finding One's Place in Working Life

2.1 Inclusion and Exclusion: Institutional, Intersubjective, and Material Manifestations

While an exhaustive analysis of the complementary terms "inclusion" and "exclusion" cannot be carried out here, at least central characteristics shall be highlighted (see also for the following Behrendt 2017). The concepts of "inclusion" and "exclusion" represent two opposite poles of social participation. When someone is successfully included, they participate in social life to a greater extent than before. The process of inclusion aims to increase social participation, which is achieved as a state after successful realization. On the continuum of social participation, inclusion and exclusion can consequently be determined complementary.

The phenomenon of social participation refers directly to socially established practices. The availability of social roles is the linchpin of social inclusion. Being included means having access to the existing social positions within an established practical context, which must be mutually recognized by all participants (including the executing agent) in their interrelated activities once the corresponding positions have been taken. According to the analysis proposed here, the extent to which a particular person is effectively included in a social practice therefore depends on their ability to take up the positions available for a specific practice. Participating in social life thus means for the individual to be included in a qualified way in the interpersonal practices of their lifeworld. Accordingly, inclusion and exclusion processes always occur relative to the existing role arrangements of a given practical context. Social practices represent the main reference parameters of social participation.

In today's working society, full membership in society is only available to those who can participate in the world of work (cf. Krebs 2002; Keupp 2005; Lelgemann 2009). This ideal of an inclusive working world requires that all working-age people effectively participate in working life, because professional participation is crucial for the status of an equal member of society. Thus, social justice requires that no one should be permanently excluded from working life. In this context, participation in the world of work means that people find their place in everyday working life, i.e. that they are professionally included. This means that participation in working life usually takes place as an employee in a corresponding professional role. The subject of professional participation is therefore jobs that are institutionalized in companies mainly as wage employment relationships.

This connection proves problematic for the group of persons who cannot fulfill the requirements for participating in working life (cf. Lelgemann 2009; Becker 2014; Becker. 2016). Some sheltered workshop employees have the opportunity to contribute their labor and thus be part of society. However, for others, especially those with intellectual disabilities and a high need for support, the opportunity of contributing to labor and thus participation does not exist. They cannot participate in working life due to a lack of support. As a result, to become equal members of society it is important to find adequate means of support that enable them to participate in (sheltered workshop) work. This is a crucial demand of social justice since work opens up opportunities for participation and social contacts to varying degrees and enables the individual to create and participate in meaningful structures. Those who cannot participate in sheltered workshop processes also experience social exclusion processes within a sheltered workshop (see Lelgemann 2009; Bächler 2020), as will become apparent later.

Inclusion can take place on three complementary levels (cf. von Kardorff et al. 2013 Chapter 2; Behrendt 2017). The first level is *institutional*. It reflects that participation is always related to certain institutionalized roles of an existing structure. Only where there are social practices that provide positions in which one can be included or from which one can be excluded, is participation possible at all. The necessary role competencies to successfully occupy a particular position determine the formal inclusion mechanism. It determines whether someone can legitimately claim participation in a role. Thus, *formal inclusion* is given when someone fulfills the institutionalized requirements for potential role holders. Since it is important for the fulfillment of formal inclusion that the individual characteristics of the inclusion subjects correspond to the institutionalized inclusion rules of a practice, it can be realized either 1) by adapting the characteristics of the actor to the inclusion rules, or vice versa, 2) by adapting the inclusion rules of the practice to the existing characteristics of the affected subject. In the first case, one can speak of "structure-preserving inclusion", in the second of "structure-changing inclusion".

The second level is *intersubjective*. It takes into account the fact that all participants must also mutually recognize each other in the roles they each take on so that these can be given practical validity. Only the general acceptance of the role bearers by their respective reference groups enables effective participation in the position taken. Accordingly, *informal inclusion* aims to ensure the necessary intersubjective attitudes between the participants in concrete interactions. This concerns the reduction of prejudices and aversions on a cognitive, affective and/or practical level (negatively framed) as well as the advocacy of mutual recognition and appreciation (positively framed).

This intersubjective level is important not only for merely nominally aspired participation but also for actually putting participation into practice. Practices structure social relations according to the respective context in temporal, material and social terms by institutionalizing generalized behavioral expectations. However, reciprocal behavioral expectations are only effectively institutionalized to the extent that claim and reality do not diverge too often. In other words, the actual behavior of all participants must also be predominantly oriented to the given role structure. The practice participants must have all the motives for taking on and fulfilling the necessary tasks and obligations that are internally linked to their mutual role expectations. A distinction must be made between two cases of informal inclusion: In the first case, a participant has an *institutional status*, but in the "eyes of the possible interaction partners from the group of the majority no equal *intersubjective status*" (Ikäheimo 2014, p. 125; own emphasis). From the opposite perspective, on the other hand, there is only an intersubjective status without a corresponding institutional status. When social positions are exercised without the normative backing of the constitutive rules of a practice or, as in the opposite case, when those are rejected for interpersonal reasons, despite formal entitlement, this represents a serious inclusion deficit that demands to be resolved in one direction or another.

The third level is *material*. It results from the fact that the specific design of the material framework of a social practice has a lasting effect on the individual's opportunities for participation. This often comes about simply because the materializations of practices are designed to fit the typical characteristics and abilities of the average role bearer. People whose individual characteristics atypically deviate from this average are sometimes excluded from effective participation simply because they cannot enter the relevant context in the first place due to obstacles that are difficult for them to overcome. For example, buildings with only stairs and narrow doors are difficult for wheelchair users to access; the same applies to buses or trains that lack appropriate assistance for boarding and alighting from. Therefore, *structural inclusion* depends on the material components of a practice being designed to be *barrier-free*, i.e., entirely usable, for all those involved. If one understands a barrier-free practice to be one in which no one who is formally entitled to participate is excluded from full participation or makes it disproportionately difficult, then a distinction can be made between various measures for implementing barrier-free practice: These measures can range from legal provisions and financial support policies to scientific expertise and raising social awareness (cf. Bethke/Kruse/Rebstock/Welti 2015). Whether someone is effectively open to access to the positions of a practice is thus, in addition to the conditions of an *institutional* and *intersubjective* nature already introduced, also a question of the *material* design of the relevant context. Accessibility is an essential structural prerequisite for effectively realizing the individual's social participation.

Social exclusion can now simply be defined in relation to these provisions: If institutionalized role requirements exclude certain individuals or groups from existing positions, we are dealing with *formal exclusion*. On the other hand, if there is a formally justified claim to participation that is de facto disregarded by those involved through negative attitudes, this constitutes *informal exclusion*. Finally, the facts of *structural exclusion* are fulfilled when the assumption and exercise of a social role are made disproportionately difficult or entirely prevented by barriers.

3 Identify and Prevent Mechanisms of Professional Exclusion

3.1 Structural Barriers

One reason for the pronounced tendency towards the professional exclusion of people with disabilities is the presence of various barriers in job environments. One such barrier is the inability to perform a particular professional role properly, despite possessing the formal role competencies. While well-known structural obstacles like stairs instead of ramps or lifts can limit access, typical barriers that are less visible in the professional context also exist. For example, if people with a visual impairment lack a computer speech output or if deaf people do not have access to a sign language interpreter, this represents a considerable inclusion threshold in many professions and thus drastically limits the opportunities for professional participation.

Barriers can be reduced through targeted interventions at the workplace to enable affected employees to participate adequately (cf. Oostrom/Boot 2013). Interventions that focus on changes in workplace design can include adjustments to working furniture, tools, materials, or machines necessary to perform the work tasks. For example, desk height that is too low can cause chronic pain, leading to a long absence of the worker. Changes in work organization are also possible, including changes in work schedules and task profiles or employee communication processes. The work situation, such as contractual regulations on working hours and remuneration, and the working environment, such as noise pollution, lighting, etc., can also be adapted to the special needs of employees with inclusion requirements to remove potential barriers to successful inclusion.

3.2 Intersubjective Exclusion

In addition to structural barriers, informal exclusion mechanisms also play a decisive role in the working lives of employees. A study commissioned by the German Federal Anti-Discrimination Agency has shown that a lack of education and information among employers and colleagues in particular, as well as a general social disregard for and stigmatization of disability and illness in general, still characterize the working lives of many of those affected: “When it comes to accessing the labor market and the employment system, as well as securing jobs for disabled and chronically ill people, manifest and even more so latent prejudices and negative attitudes act as decisive” exclusion mechanisms (Kardorff/Ohlbrecht/Schmidt 2013, pp. 28–29; own trans.). In particular, the (assumed or actual) reduced performance capacity of those affected plays a significant role in their lack of recognition and exclusion in the workplace among colleagues and superiors.

An important instrument of intersubjective inclusion to counteract this and promote acceptance and appreciation of employees with disabilities and health restrictions are regular training courses and sensitization measures, both for colleagues directly affected and for the other people generally involved in the company. Changes in the work situation and organization must also be considered at this level. In addition to the reference to an adapted remuneration system to “reduce envy and competitive thinking”, Niehaus (2005, p. 78, own trans.) also observes that “acceptance of limited performance […] is most likely to be guaranteed if the employee […] has already belonged to the group concerned for a long time and if there is no increased number of employees with handicaps in one area, but an approximately equal distribution across different working groups”.

3.3 Institutional Requirements

Structural and informal inclusion measures in a company can improve the occupational participation situation of people with disabilities. However, successful rehabilitation aimed at ensuring long-term participation in working life cannot be achieved without precautions against formal exclusion mechanisms in the world of work. The personal aptitude of the worker is a decisive factor for the success of formal inclusion. Thus, employees must meet the specific performance requirements of the related job to make a productive contribution to the company. In a general sense, these necessary role competencies of a professional role refer on the one hand to the necessary technical rules of conduct or procedures. According to Claus Offe (1970, p. 29, own trans.), this can be understood as the "totality of physical performance, performance skills and performance knowledge gained from experience and practice", "which are necessary at a particular workplace to be able to perform the corresponding work task". On the other hand, they include the necessary normative orientations to fulfill the respective role in the company. This in turn can be summarized as "all norms, values, interests, and motives […] which are expected to be followed in the institutional framework of the work process" (ibid.; own trans.). The role competencies mentioned above express what can also be called the applicant's "personal suitability" for a corresponding professional role. It must be possible to cope with these demands on the execution of work independently, otherwise the person concerned is not sufficiently competitive as an actor in the internal and external labor market.

At this level, two dominant strategies for formal inclusion in the working world exist: the internal search for a free, performance-adequate job and/or the early and permanent professional qualification of employees. The aim of the search for a vacant position with performance adequacy is the job-preserving new placement of affected employees in the company. As Schmal and Niehaus (2004, p. 228) state, the willingness of the direct superior, who is usually responsible for this, is decisive for the measure's success. In order to determine adequate jobs, the ability profiles of the affected employees must be compared to the requirement profiles of the existing jobs, for which the necessary technical infrastructure is rarely provided. It is therefore much easier for highly or multiply qualified employees to find a suitable job than for less qualified employees, which is why a high degree of internal mobility must be a prerequisite for inclusion success (cf. Ibid., p. 229). Since the search for jobs with adequate performance is more successful if those affected are appropriately qualified, vocational (further) training offers are critical preventive measures that increase the chances of successful reintegration. The European Commission created a corresponding framework by giving lifelong learning a prominent status as a so-called cross-cutting objective (Commission of the European Communities 2003; cf. Niehaus 2005, p. 78).

In this context, technical assistance can also be a suitable tool for promoting professional participation. Its use in the workplace improves the users' performance, as shown shortly.

4 Technical Assistance to Support Work Participation of People with Intellectual Disabilities and High Support Needs

4.1 Technical Assistance Design and Development

In the area of assistive technology, innovations and changes are needed for people with intellectual disabilities (Sauer, Parks and Heyn 2010). Previous research shows why particularly people with intellectual disabilities could benefit from technical assistance in assembly operations. This study presented below, therefore, includes people with intellectual disabilities within a sheltered workshop.

This section of our paper describes the evaluation of a technical assistance system for people with intellectual disabilities developed within a multidisciplinary research project. The employees receive assistance from the system, which provides a memory aid using in situ projection during the work process. The assistance system consists of a projector, which displays contour visualizations of instructions directly into the worker's field of vision (in-situ), and a depth sensor, which monitors the execution of work activities in order to give context-aware feedback (compare Fig. 1). Employees with intellectual disabilities could thus perform complex assembly processes step by step, as the system recognizes mistakes and gives subsequent steps only if previous steps have been carried out correctly (compare Fig. 2).

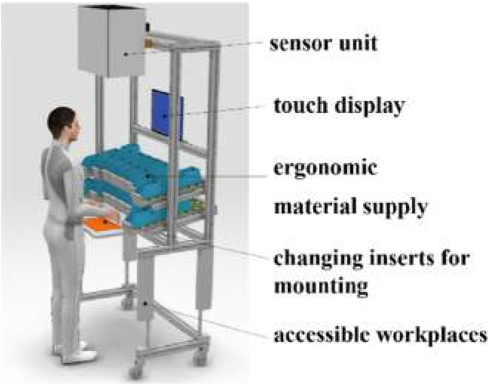

Fig. 1. The assistance system (Bächler, Bächler, Kölz, Hörz and Heidenreich 2015).

Fig. 2. The assistance system using in-situ projection (Bächler, Liane).

4.2 Field Research Process

The present field research process adopts a multi-method research strategy and uses exploratory research methodology to support knowledge acquisition (cf. Amann and Hirschauer 1997). Based on a field study and using differentiated methodological approaches, for example participatory observation, field interviews, problem-centered interviews with people with intellectual disabilities, and expert interviews with specialized staff in a sheltered workshop, the use of technical assistance to promote work participation for people with intellectual disabilities and high support needs were investigated. The results of the 13 interviews with sheltered workshop employees with intellectual disabilities and a high need for support provide an insight into the process-open research process and clarify the subjective perspective of the target group. However, methodological aspects cannot be dealt with in detail here (cf. Bächler 2020).

5 Results

5.1 Promotion of Independent Work Participation Through Technical Assistance

The following results show how the use of technical assistance to support work participation is experienced from the users' point of view, particularly sheltered workshop employees with intellectual disabilities and a high need for support – and how this affects this group of people with regard to the promotion of work participation. The focus here is on the experiences of this group of people with regard to promoting work participation. The results represent only an extract of the research process and can be seen in further detail in Bächler (2020).

Field observations and interviews document the effects with regard to the work participation of sheltered workshop employees with intellectual disabilities and a high need for support. This analysis clearly demonstrates that the use of technical assistance encourages work participation for this group of people. Through the technical support and its guidance, they are enabled to perform the simplest sequences of work activities typical in their working environment (here: assembly tasks) and successfully assemble a product under technical instruction.

The use of technical assistance for sheltered workshop employees with intellectual disabilities and a high need for support meets with *positive astonishment* within the sheltered workshop. On the part of the specialized personnel the *surprise* is clearly due to the fact that exactly the group within the sheltered workshop considered as *"only able to participate in work with difficulty"* (FG_FE_Fp_2) is now able to actively participate.

Technical assistance shows that work participation is not inevitably linked to personal characteristics, as these do not always depend on individual but also on social, societal and technological circumstances, such as adequate support for work participation.

The results from observations at different time periods and different types of conversations provide information on the needs and necessities of the sheltered workshop employees with intellectual disabilities and a high need for support. They directly indicate the positive promotion of work participation through technical assistance for this group of people in the sheltered workshop.

Independence through technical assistance

At the beginning of the interviews, the interviewees were asked about their previous work participation within their working environment, the sheltered workshop. All interviewees pointed out that they were successfully supported in their work participation by the offer of technical assistance.

The technical assistance helped all those involved in the study to carry out an assembly process for a product with this form of instruction enabling them to participate. The use of technical assistance makes it possible, through adequate instruction, to carry out simple work activities independently, something the group of people was previously not able to do in this manner or form.

At many points in the field surveys (in field talks and interviews), users of technical assistance have reported that they can now work *"on their own"*.

These statements refer to their own performance of the work activity, which they can now perform independently with the help of technical assistance. In a field interview a user mentions:

"I did that very well. Made it myself" (FG_FP_I_9).

A positive accomplishment through successfully independently performed work activities enables regular success experiences and recognition through appreciation for the individual. It also made previously hidden skills and individual knowledge visible.

A successful independently executed work activity brings about self-esteem which goes far beyond working hours, as the following interview excerpt documents:

> *"I told the dormitory that I am working at a new workplace and how many parts I have already made. They can't believe it (laughs)" (FP_II_PZI_2).*

By adequately supporting the group of people to participate in work, they experience a feeling of independence. The field discussions and interviews highlight that the group of people analyzed is also expanding its social circle.

Safety in the performance of work activities with technical assistance
Sheltered workshop employees with intellectual disabilities and a high need for support report a feeling of security when using technical assistance.

> *"I feel quite safe. The system shows me what I have to do. I can trust it. Before I never knew what to do and was always unsure if I was doing it right. Sometimes I always did everything wrong. Then the part was also wrong. I only noticed that at the end"* (FG_FP_I_4).

This indicates that people with intellectual disabilities and a high need for support require close guidance, which is difficult to ensure within the working world. The assistive technology to participate at work provides user-centered guidance that enables users to experience safety, even when performing multiple tasks.

> *"Up to now, these people were only able to carry out activities consisting of very few steps. Even these were a challenge for many of them, since it is always a matter of maintaining a correct sequence or the correct placement of individual parts. Often, however, the order or the correct placement is forgotten, so that nothing is done for a long time. This unsettles our employees, of course, if they realize they are doing something wrong or cannot retain what should be done and forget it over and over again" (FG_FP_I_Fp_7).*

Social isolation and disregard by not supporting work participation of sheltered workshop employees with intellectual disabilities and high need for support within the sheltered workshop

Through the use of technical assistance, a group of sheltered workshop employees becomes visible, who up to now have spent a large part of their day not participating in work, completely isolated from the rest of the sheltered workshop group.

These are not spatially isolated as they sit in the middle of the activities, i.e. in a sheltered workshop production and manufacturing hall, but are clearly recognizable, have no share of sheltered workshop work and are thus excluded by their special position.

The interviewees talk about experiences of disregard within the sheltered workshop. They relate these experiences to the fact that they were unable to work and that this inability meant they were also not part of the sheltered workshop 'community':

> *"We are not paid as much attention as the others who can work" (FP_II_PZI_1).*
>
> *"They can't be bothered with us that much. It always has to go fast. And then it is too fast for me" (FP_II_PZI_4).*

Likewise discussions with technical personnel highlight the situation of this particular group:

> *"Sure, we can't take care of everybody at the same time. Everyone is important to us. No question about it, but the orders we have taken on have to be carried out. The strong employees are going up the wall, if bored or there are problems with the machines. We have to look after them primarily. (Extract from FG_FP_II_Fp_6).*
>
> *"A lot has happened in recent years. There have been many concepts that should have made working possible for the weakest employees, but many remain unsuccessful" (FG_FP_I_Fp_4).*

Enhanced visibility of a previously isolated group of people by promoting work participation through technical assistance

All interviews and field discussions show that the isolated group of people analyzed within the sheltered workshop – although somehow part of the sheltered workshop community are *"not quite"* integrated (FP_II_PZI_2).

Interview participants confirm field observations in the following words and refer to the help through technical assistance to realize the work participation:

> *"I can work with the light signals. Without light signals I do nothing. Then I always just sit here"* (FP_II_PZI_3).

> *"That helps me. I always know what I have to do"* (FP_II_PZI_1).

Field observations, as well as field discussions with technical personnel from the sheltered workshop, prove that there were previously almost no target group-specific offers for this group to promote support and work participation.

Meaningful work participation for sheltered workshop employees with intellectual disabilities and high support needs through the use of technical assistance
The sheltered workshop employees who worked with the help of technical assistance commented, that they *"now also do something useful"* (FP_II_PZI_2). These and other similar remarks show that work participation through technical assistance can serve a meaningful purpose, as it enables multi-step work sequences to create a product for this group of people.

Identification with the product was also noticeable and the pride in having produced it:

> *"Then everyone in the DIY store will be happy if they buy that one. If they knew who made it! (laughs)"* (FG_FP_II_N_1).

With technical assistance, sheltered workshop employees with intellectual disabilities and a high need for support are on the one hand enabled to participate in work at all and on the other hand supported to participate in much more detailed work activities. This enables the production of a complete product. Without technical assistance, they are given monotonous work activities through highly fragmented task steps whose meaning and purpose they cannot comprehend.

6 Conclusion

We have examined inclusion mechanisms and obstacles to employment and rehabilitation. The multi-dimensional nature of this issue has shown that measures must be taken at a formal, informal, and structural level to increase opportunities for participation for people with disabilities. *Firstly,* targeted interventions were suggested for the workplace in question to reduce structural barriers. *Secondly,* the importance of intersubjective inclusion strategies to overcome prejudices and negative attitudes towards those affected has been emphasized. *Thirdly*, as we have highlighted, lasting participation in working life can only be ensured if, in addition, institutional precautions are also taken, such as the search for vacant jobs in the company that are suitable for the employee's skills, as well as offers for lifelong vocational training.

The subject-oriented approach within the present work assumes a creative ability in each person. This speaks out for the necessity and addition of innovative ideas regarding the individual perspective of action in order to promote participation in work for people with intellectual disabilities and a high need for support as well, and against exclusive care of them. The empirical results have shown that using technical assistance is a possible impulse for change regarding promoting participation in work.

Focusing on people with intellectual disabilities and a high need for support is required in order to meet the often postulated goal of an inclusive society. Since this is a demanding long-term task for society as a whole, actors in various working environments and the legislator are challenged to adapt structures and make available necessary resources to ensure successful social participation for all.

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Designing Explainable and Controllable Artificial Intelligence Systems Together: Inclusive Participation Formats for Software-Based Working Routines in Industry

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Abstract. "This is what it would look like if your AI (Artificial Intelligence) system was explainable to and controllable by you." With this title, a co-creation workshop was hosted by the Berlin-based Institute for Innovation and Technology (iit) on December 1, 2021. The workshop addressed the question of how artificially intelligent systems can be designed to be explainable and controllable in collaboration with different user groups. The workshop tested sociotechnical design methods for the participatory inclusion of potential users in the development process. An interactive matrix helped to collect ideas from participants and differentiated sociotechnical aspects on a technical, organizational, and human level.

As a second method, drafters (a.k.a. graphic recorders) accompanied the workshop and visualized the computer system´s interface according to the discussion. The following article introduces these two workshop methods, presents the results and gives recommendations based on the experiences for future workshops. The workshop format also addresses the challenge of operationalizing ethical principles in the design of AI.

Keywords: Participatory design · Artificial Intelligence · Explainability (XAI)

1 Project Framework, Preliminary Work and Motivation for the Workshop

The co-creation workshop described in this chapter is part of the project "Digital Sovereignty in Industry" addressing the design of transparent and informed working conditions for skilled workers in industrial work environments who use complex, digital systems. The iit Berlin is running the project since 2019. Ahead of the workshop, the

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institute analyzed current trends and innovations for a deeper understanding of digitized industrial workplaces: In 2019, interviews were conducted with experts from academia and industry who engage in the design of user-centered digital workplaces (Pentenrieder et al. 2020). In order to complement the expert opinions with a practical perspective, the iit conducted workplace studies at companies in the German tool making and mold making industry in 2020. Ethnographic methods (Suchman 1995) helped to explore the use of digital technologies in everyday working routines. During visits to several medium-sized companies (SMEs), workers were accompanied in their everyday work practices. They were interviewed directly in their work environment about their wishes for and concerns about a digital future (Pentenrieder et. al. 2021). The user-centered approach revealed, on the one hand, concerns about a lack of transparency and about larger dependency and restrictions on work practices due to increasingly complex IT systems. On the other hand, the employees noted that there are not yet enough best practice examples for complex technologies that enable skilled workers to stay knowledgeable about the workings of complex machines. Clearly, explainability and controllability play an even greater role once systems start using software components containing artificial intelligence (AI).

Based on this information from the practical work environment, the iit Berlin developed a workshop format to inform practitioners about innovative technologies in a user-oriented way and to make the technology discussable between different stakeholders. It was the interest of the practitioners that AI components and their value for daily work routines are discussed (a) in the context of particular applications. Only this closeness to industrial use cases allows the evaluation of the new technologies´ specific value for the working environment. Furthermore, (b) new systems must be usable for teams with different levels of knowledge and different technical backgrounds. Based on these needs, the authors developed a participatory online workshop and subsequently tested it. In all phases, co-creation principles and participatory design formats were applied (Prahalad and Ramaswamy, 2004; Cech 2021).

2 Theoretical Basis for the Workshop

In line with the preceding assessment of user requirements in the German toolmaking industry, the workshop on December 1, 2021, aimed at testing a format to elaborate the explanatory and controllable capabilities of complex IT systems. The workshop embedded digital methods that were increasingly used during the Covid-19 pandemic (for the workshop concept, see Pentenrieder et al. 2021; Pentenrieder and Hartmann 2022). The event software "WebEx" was combined with a digital whiteboard of the collaboration platform "Miro". The workshop was open to different user groups and free of charge. This allowed everyone interested in AI systems integrated into industrial work environments to participate in the workshop in order to develop scenarios for explainability and controllability for different user groups. Representatives from business, politics, and science received explicit invitations to the workshop.[1]

[1] A recommendation for future workshops would be to select the participants only from one company so that different departments can share their technical and social experiences with the same product (see chapter 4).

The workshop aimed to analyze workplaces as sociotechnical systems. Therefore, the participants' ideas and experiences were arranged along a matrix of socio-technical aspects. As a second method, graphic recorders accompanied the discussions and visualized aspects of the working environment. They focused the content of the graphics, particularly on situations where new explanations were needed. The participants could see and comment on the visualizations live alongside the discussion (see Fig. 2).

	Socio-digital Sovereignty		
	Transparency and Explainability	**Confidence of Action (Efficiency)**	**Freedom of Action (Divergence)**
People	**Basic digital skills** Which skills are needed for being able to understand basic structures and processes of the technological system?	**Task-related digital skills** Which skills are needed for being able to operate the system with a high level of confidence and efficiency?	**Broad digital skills** Which skills are needed for being able to pursue a range of goals, actions and operations with the system?
Organization	**Transparency regarding tasks and roles** Is it clear who has which tasks, responsibilities, and how different roles relate to each other?	**Combination of tasks, social support** Are individual tasks and interactions of different roles combined in a way that supports confidence of action?	**Range of discretion** Which degrees of freedom and range of discretion do people have?
Technology	**Transparency and explainability of technology** Is the system in its structures and/or functioning transparent to the users, or are (approximated) explanations for these structures and processes available?	**Technical reliability and resilience** Is the system reliable, will it operate also under adverse conditions?	**Freedom of action as supported by the technology** Does the system offer and support different courses of action or different styles of action to the users?

Fig. 1. Interactive matrix based on sociotechnical aspects (own illustration)

The matrix' structure relates to work in the field of ergonomics, for example by Mumford (2006) concerning a sociotechnical approach based on values of democracy (cf. Also the Scandinavian concept of 'industrial democracy', Emery and Thorsrud 1982) and group dynamics concepts (Mumford 2006). The 'original' school of thought dates back to the Tavistock Institute of Human Relations (Trist and Bamforth 1951; Mumford, 2006; Cherns 1976). The core postulate of this approach is "the joint optimization of the social and technical systems" (Mumford 2006). This implies (at least implicitly) a two-tiered structure of sociotechnical systems, with both social and technical subsystems. More modern approaches select three sub-systems: Technology, Organization, and People. Organizations as social entities and human beings are considered here as sub-systems of organizations; this approach is also applied in the matrix in Fig. 1. Besides these basic concepts from sociotechnical systems theory, the matrix focuses on transparency, explainability, and controllability. Controllability is split into efficiency and divergence, in the sense of psychological control and action regulation theory. In this context, efficiency refers to an environment where specific actions lead with high predictability to specific results. Divergence means that different courses of action leading to different ends are available (see Fig. 1; Oesterreich 1981; Hartmann 2021; Pentenrieder et al. 2022; further references can be found in the literature).

To put these theoretical ideas into practice, the workshop used graphic recording as a method that carries both technical information and social knowledge in the same way:

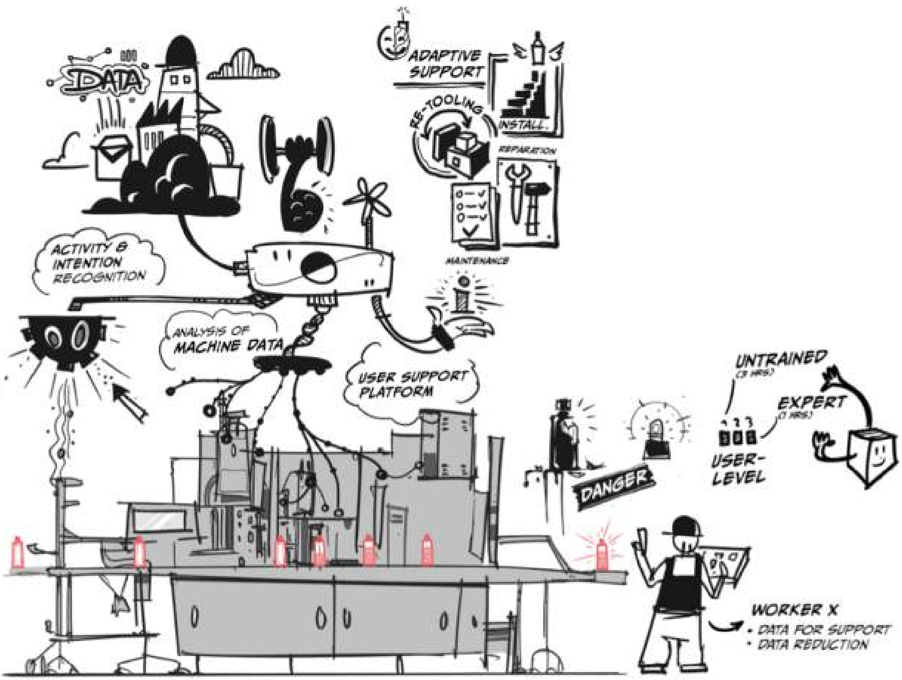

Fig. 2. Graphic recording as an interactive method to discuss work environments inclusively (own illustration based on Visual Facilitators)

The approach of artifact analysis, according to Lueger and Froschauer (2018), enables a closer look at the socio-technical system of AI-supported processes in organizations/companies to understand the concrete meaning for technology, humans, and organizations in detail. The two authors define artifacts as a mediating and coordinating instance (e.g., road signs) between actors as well as a supporting and orienting instance (e.g., medical prostheses) (cf. Lueger and Froschauer 2018, pp. 25f.). AI-supported software systems within a company can be understood as such an artifact. As such, the AI-supported software systems merge with the knowledge of the respective participants using them (Lueger and Froschauer 2018, p. 23; cf. Also Bateson, 1985, p. 582; Carroll & Campbell 1989). Lueger and Froschauer attribute great potential to artifacts for indirect learning processes, “in that we can save ourselves laborious research, experiments, or experiences because others make their insights available to us.” (2018, p. 22, own translation).

Artifact analysis helps to investigate the structural influence of artifacts on individual actions as well as on interpersonal relationships (cf. Lueger and Froschauer 2018, p. 78). It raises questions like:

- Which actions are delegated to the new AI system – and thus change the actions and competencies of the humans that surround the technical devices?
- How must the actions of humans adapt while interacting with the systems? What further training should be offered?
- What kind of support do users of AI systems need? At the beginning of the day, the machine could ask how much support is needed: little to a lot as by the user's choice (e.g. selectable through a slide control, see Fig. 6). During the day, the machine could keep asking back, whether more or less support is needed.
- With regard to the different groups of people who use the technology within a company, it is also important to consider in which situation the new system will be used: Which user (group) needs which kind of functional interface and appropriate information from the system? Typical application characteristics of the technical system in terms of places, times, social circumstances, events, or processes must be considered as well.
- In which contexts could the AI system be used? How does it differ from currently used artifacts and techniques? What is the added value of the new technology for the investigated context?
- To what extent do artifacts structure and influence social settings?
- Structuring of social spaces and associated calls to action
- Structuring of action sequences
- Influencing social relations
- Influencing communication
- What forms of conception and history of acceptance are associated with the artifact?
- Integration into cultural developments
- Function of the specific artifact
- Context of the discussion about (similar) artifacts
- How does the conception of the artifact change…
    - … conditions for acceptance?
    - … temporal processes with regard to social or cultural integration?
- The importance of integration for social coexistence (Is the new technology automatically the better solution? > Who does it exclude? > What interfaces exist between old and new methods?)?
- Stories about previous artifact versions (involve senior employees and using their wealth of experiences)?

These questions show that the social dimension of a technical system does not stop at the user interface and, respectively, at the display of a system. The organizational level also needs to play a part in the design of the explainability and controllability of a system. Examples are the availability of social support at the workplace in using the AI system and also the involvement of the works council in integrating new software.

In addition to the software implementation, continuous training must be considered, financial resources must be provided, and additional effort needs to be applied in order to enable explainability and controllability. To that end, co-creation workshops are ideally integrated into design methods of intelligent systems and thus create additional value. With this in mind, this paper shows how specific characteristics of intelligent systems can be developed with the suggested workshop format for three exemplary applications.

3 Case Studies, Discussion, and Results

Case study 1 (Fig. 3) was provided by Dortmund University of Technology and features an application from the brewery industry. The project wants to trace back the taste quality of beer to its ingredients and to the parameters of the brewing process. Therefore, the software system processes more than 50 parameters for the quality of water, hops, malt, and yeast.

Fig. 3. Predicting the taste of beer with AI (own illustration based on Visual Facilitators)

Case study 2 (Figs. 2 and 4) focused on the various maintenance processes of a bottling machine and was organized by the University of Stuttgart and the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA). Both organizations develop a new digital system to facilitate the setup processes of bottling machines. A guided error analysis supports workers with different levels of knowledge in their tasks during maintenance.

Case study 3 (Fig. 5) was from the automotive industry, provided by the University of Bamberg, Fraunhofer Institute for Integrated Circuits (IIS), and Continental AG. It deals with new software that supports engineers in programming the locking system of a trunk lid. The particular challenge is that, as in the case of the brewery, many parameters affect the result and have to be traced back. Factors that affect the closing function of the trunk lid include tilt of the car, outside temperature, and humidity. The trunk lid must close securely under all conditions but also let go when, e.g., a finger is in the way.

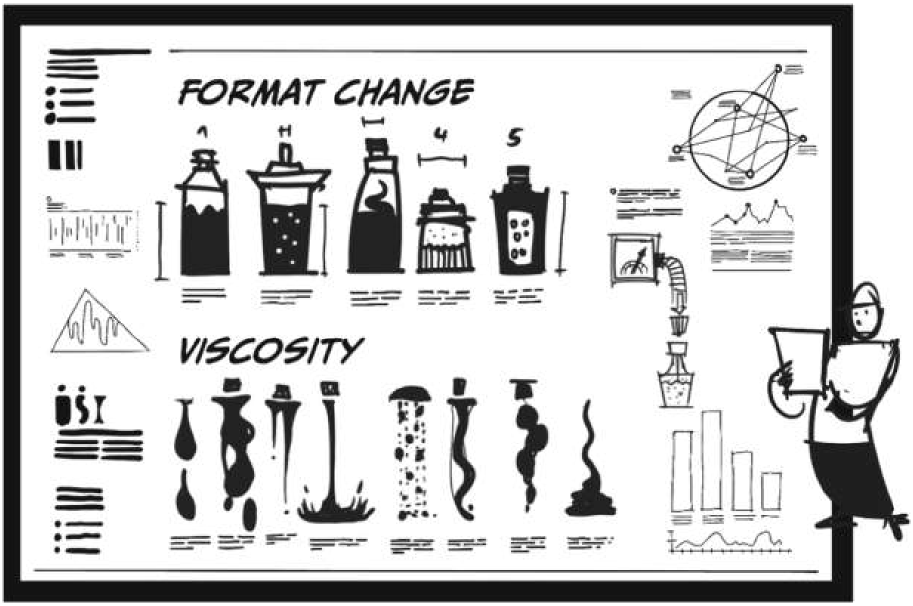

Fig. 4. How could the change of a bottle format look like for the maintainer? (own illustration based on Visual Facilitators)

Finding the right combination for this is a major challenge. Aspiring engineers are to be supported here by an AI system that is fed by the knowledge of more experienced engineers.

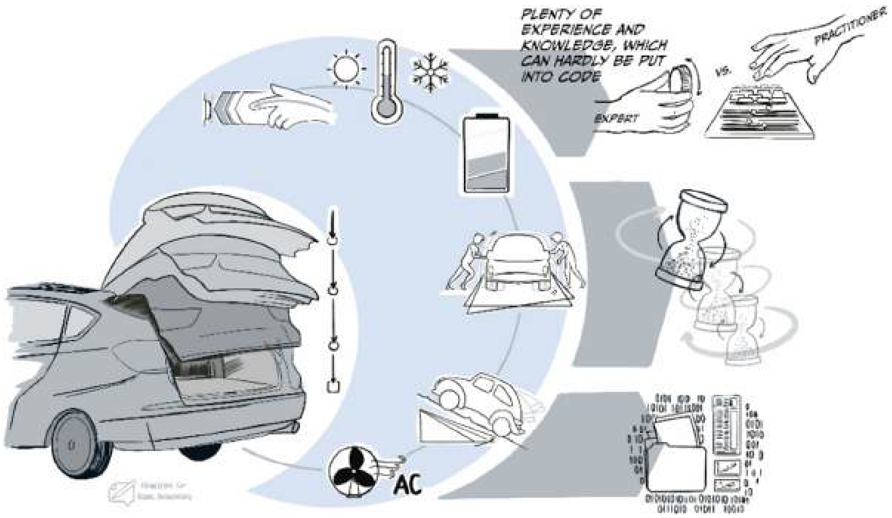

Fig. 5. Parameters of for the locking system of a trunk lid (own illustration based on Visual Facilitators)

All three projects work with AI-based technologies and at the same time pay special attention to the explainability and controllability of their systems.

3.1 Integration of Different User Groups

All three case studies have in common that experienced specialists contribute their experiential knowledge to the machine learning process of AI systems and pass it on to less experienced colleagues. Furthermore, in all examples, workers with low to high technical expertise encounter very complex systems that are not readily self-explanatory. Thus, explanations are absolutely necessary for a safe operation of the systems.

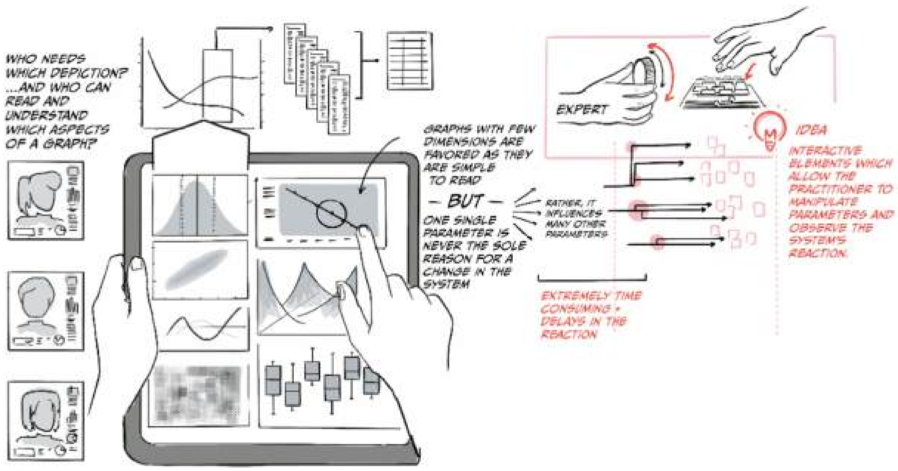

Fig. 6. Multiple views of different user groups. Who needs which explanation?(own illustration based on Visual Facilitators)

Figure 6 shows the result of the discussion about the multiple views that support different user groups in finding an explanation or controlling the system. Each user might have different questions for the system; therefore, any explainable AI is guided by each user differently. Moreover, information requirements vary depending on the role of the user. The graphics on the left side of Fig. 6 exhibits how information changes depending on whether the system addresses management staff, trainees, or trained users.

The management sometimes does not have a technical background but needs the condensed interpretation and main messages from the data and, at best, application examples – like data thresholds of decisions (see f.e. counterfactual explanations by Wachter et al. 2017) – to be able to communicate the meaning of a decision made.

Trained professionals will also use the system. They need additional views for interpreting individual data points, for example to identify (causal) relationships in complex data. The participants developed transparency strategies for this purpose (see top right in Fig. 6). In complex systems, a parameter never stands alone but is dependent on influences by other parameters. The case studies all concluded that with the use of artificially intelligent systems, the (visual) representation of independent and dependent parameters – whether in relation to the trunk lid or in relation to the taste of beer – is a key challenge for interface designers.

A third and different view is required for new employees who need training in interpreting output parameters. For this purpose, the participants developed the idea of an interactive element for new employees that allows them to move parameters and directly observe and understand the effect of changes in the system (see Fig. 6).

3.2 Embedding Human Skills in Standardized Digital Production Processes

Existing debates about which kinds of work can be automated continue in the development of explainable and controllable technical systems. Highly standardized processes and processes to which e.g. lean management methodologies have already been applied and which follow more rigid rule sets are easier to automate and consequently also easier to explain than complex processes or processes that have not yet been subject to process standardization. Accordingly, it is important that processes in which complex digital systems are to be used first undergo, ideally iterative, standardization. The company has the responsibility to be aware of these facilitators at an early stage instead of perceiving AI as a panacea and making excessive demands on the implementation.

A complementary aspect in the discussion concerns the tasks and roles on an organizational level. First of all, clarity must be achieved about the area of responsibility of the specific worker. To reach better explanations within automated processes, the person's tasks and roles in the process must be defined. For IT developers, this is usually an indispensable basis for assigning "rights" to a machine, so that the person can then be assisted in a task-appropriate manner. For this purpose, a process must be clearly divided into steps and the corresponding roles for planning, monitoring, and execution. In the workshop, possibilities were discussed, regarding how an explainable AI system could also pave the way to further qualifications and thus actively support the users in on-the-job-training (see Fig. 6 the training to interpret parameters).

3.3 Data Protection and Ethics

As with any form of data collection in the work context, fundamental questions of data privacy arise when collecting and processing data by and for AI systems. This is also the case in one form or another in the three projects discussed. If AI is fed with data from video surveillance of the work of experienced workers, concerns for privacy and ethical issues of performance monitoring arise.

When it comes to IT knowledge, developers of AI systems must also critically reflect on the assumptions that they consciously and subconsciously make about users. In case of doubt, certain biases arise from prejudices, which can be an obstacle to the design of a sustainable acceptance of the system. This can also be something as banal as the distinction between right-handed and left-handed people, which can lead to actions by one of the two groups perhaps not being recognized by the system. Organizations and system developers should not guide themselves by the principle of the 'dumbest possible user', but should actively deal with the needs of the users and design systems in such a way that they provide optimal support to all users and thus lead to user empowerment.

4 Outlook: Potential for Further Development

The aim of the workshop was to make AI systems accessible to a broader audience and discuss in an open manner how AI is involved in working routines and where explanations are required. The lively discussions showed that explanations of complex AI systems should be designed with the participation of different user perspectives. Such a process can be successfully supported by socio-technical methods like the analysis matrix presented here and graphic recording. In the following, the results of these methods are discussed with regard to further workshops based on the experience from the first workshop.

Graphic recording as a starting point for interaction design?
Graphic recording was very helpful to facilitate the exchange across disciplinary boundaries by allowing participants to share their ideas with each other using visual aids. The workshop led to the experience that visual results can be used for the joint development of user interfaces and the discussion of working with complex technologies.

The method of graphic recording supports the participation process in two dimensions. First, the graphics bundle the ideas from an open discussion. The method serves as an instrument to structure the workshop by focusing on common views and technical details at the same time. The graphics (see Figs. 2–7) developed during the workshop serve as a projection surface for discussion subsequent to the workshop. As a second function, the graphics show how explainability and controllability could work in a specific situation – therefore they serve as a product for further work of interaction designers.

Furthermore, accompanying the workshops with graphic recordings, on the one hand, enabled an exchange about technical details but, on the other hand, also led to a transfer of ideas between the case studies. Moreover, it enabled the elaboration of generally valid quality criteria for explainable AI. These boil down to different user groups needing access to internal information of complex systems and having to be addressed differently by the interface. An appealing user interface is essential for the communication with users who are not technicians. Also, the visualization of complex data streams requires new creativity: It is a challenge to balance between complexity reduction and representation of the actual complexity (see Fig. 7).

Testing the online participation format based on collaboration and graphic recording is one possibility for bringing together diverse perspectives and expertise to address needs for technology design. This confirmed our assumption for the workshop that visualizations in particular can be used to address and activate different user groups to join a technical design discussion. The specific question of how to design a button on the user interface and where to put it makes interface design accessible to people who might otherwise not feel confident enough. However, one of the most important lessons learned from the workshop is to plan and specifically invite people as heterogeneous as possible to achieve truly interdisciplinary participation. Especially for online formats, special attention must be paid to the participants´ commitment by issuing personal invitations.

The workshop examined the following opportunities for graphic recording. At the same time the aspects are also challenges for the further workshop development.
Graphics…

- create a tangible basis for follow-up discussions

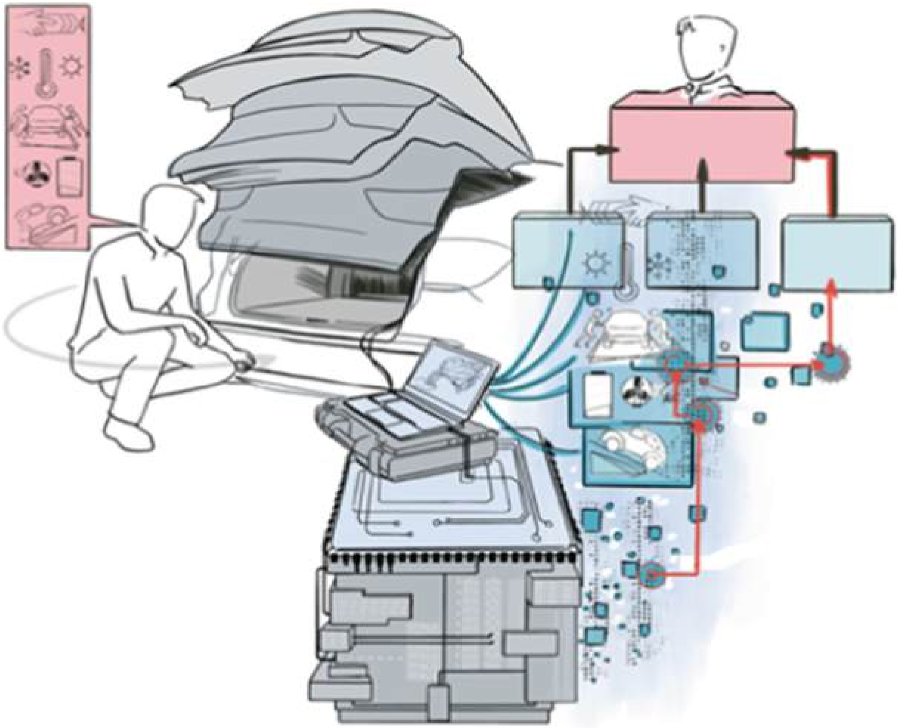

Fig. 7. Balance between reduction of complexity and display of actual complexity (own illustration, based on Visual Facilitators)

- are easy to understand
- promote a strong reduction of what the system actually is

- may reproduce but also illuminate unspoken basic assumptions and biases
- make it (presumably) difficult to present issues such as privacy or user autonomy

Regarding the 3×3 analysis matrix – combining the sub-systems (technology, organization, people) of sociotechnical systems with aspects of transparency, explainability, and controllability – it became evident that this is an excellent tool to structure questions and demands identified by the workshop participants. In the future, it will be investigated whether this conceptual structure is usable for developing a formal method for the evaluation and certification of AI applications at industrial workplaces.

Who should participate in *co-creation workshops?*
The workshop tested a contemporary method of exchanging views on what explainability and controllability mean to different groups of users and what such explanations should look like when it comes to complex IT systems in industry. One important finding was that the programmers who are designing the system's technology should not be responsible for explanations as well. Rather, a level of mediation is needed that translates technical aspects into the language of different user groups (and takes into account their social, e.g. organizational and individual needs/dependencies). Still, there are not enough levels of mediation integrated into the design of XAI systems due to time and financial restrictions. The aim of the workshop was to develop example scenarios in which the explainability and controllability of IT systems can be discussed.

Especially digital workshops have the potential to integrate non-technical participants into discussions of technology design. This group is essential for the development of explanations because everyday users mostly do not have the technical background that programmers of the software have. Users without an IT background therefore often have to ask questions about the system's way of functioning. Consequently, it is particularly necessary to receive their valuable opinions so that a wide range of users can understand complex IT systems in the future. For industries such as mechanical engineering, participation can also address problems of skills shortages.

Future workshop formats should focus even more on problem-oriented solutions: The workshop discussion should be initiated with a problem statement or needs and wishes for improvement of shop floor workers using a specific software technology. Questions like *What support would be helpful for your everyday work? What software components cause problems in your everyday work routine?* support this discussion. To conclude, the general advice should be to try to solve a problem with the simplest possible technological device (possibly without AI). However, if the best solution seems to be explainable AI, it is highly recommended to choose a participatory approach for its development.

Recommended questions for further workshops may include, but are not restricted to:

- How can I implement this workshop format as a company or as a consultant in the company?
- Which company departments should be involved in such a workshop (e.g. research and development, human resources, managers, workers, employee representatives, etc.)?

- How can the graphics from the workshop be productively used for the subsequent process of interface/interaction design?
- Which costs and benefits result from integrating participatory workshops for the software implementation?

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Digital Work – Transforming the Higher Education Landscape in South Africa

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Abstract. There are twenty-six public universities in South Africa. Yet, there is no digital transformation in most higher education workplaces. In some universities, digital technologies are advanced, and in others, they are not. The education landscape is partially transformed, and in others, it is a work in progress. Therefore, the study explored the digital environment in the twenty-six public universities in South Africa by using qualitative methods and found that the digital environment in higher education poses digital inequalities that make it difficult for academic staff to work smarter across the board. The playfield is not seamless and given the digital society of a new normal, digital work deserves close attention. The study concludes that digital work in South African higher education requires digital transformation to enable the academic staff to optimally work from everywhere in any educational environment to maximize productivity in the advancement of the academic project and to produce globally competitive and locally relevant graduates.

Keywords: Transformation · Digital transformation · Digital society · 4iR · Technological revolution

1 Introduction

The academic staff in the 21st century should be privileged and well-off to find themselves living in a digital society and teaching in a time of rapid educational change and adaptation. The use of chalkboards, chalk and talk is a thing of the past transformed from physical contact to an online presence or a hybrid thereof. Academic staff can now use smart boards instead of dry-erase boards. The limits of the physical classroom teaching and learning have transcended and transitioned to the limitless information superhighway. Digital technologies openly advanced access to education and how academic staff and students could virtually connect and transmit knowledge irrespective of their geographical spaces and time zones. The use of these technologies in the classroom should be seen as complementing the academic staff's role in teaching and learning (Masenya 2021:10).

However, despite this breakthrough, the higher education landscape in South Africa was for a long time unlevelled. The apartheid education accounts for this inequality

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as out of the twenty-six public universities, some are historically disadvantaged institutions on one hand while others are historically advantaged on the other hand (Yende 2021:59). There are also conservative and liberal universities. Yende (2021:59,65) points out that the inequalities within the institutions of higher learning were arbitrarily perpetuated by the distinction between historically white universities (the University of Cape Town, University of Pretoria, Rhodes University, University of Johannesburg, Stellenbosch University and University of the Witwatersrand) and black universities (the Sefako Makgatho Health Science University, University of North-West, University of Venda, University of Fort Hare, University of Limpopo, University of Zululand, University of the Western Cape, Walter Sisulu University among others). The structural classification of these institutions compromised the quality of education. For example, most rural-based institutions experienced poor network connectivity and this dismally disrupted digital work and learning.

Digital transformation of the education landscape is confronted with challenges and new opportunities both locally and globally. The use of digital technologies by academic staff at work is key to advancing innovative teaching and learning. While there is a gradual increase in the use of these innovative technologies in South African universities, there is still a long way to transform the entire educational landscape. One of the impacts of digital technology necessitated the need for academic staff to acquire 21st-century skills but they are not there yet (Masenya 2021:1).

During the post-Covid-19 period and the fourth industrial revolution (4iR), it is given that digital society is irreversible and thus requires a digital transformation of the education landscape to offer quality education using technological interventions. The interventions could enable students to access education without any hassles. According to Ohei and Brink (2019:4) and Simbarashe (2021:285,291), many universities have adopted technological tools and applications as part of their teaching and learning because Covid-19 and the 4iR conspicuously expressed the importance of hybrid teaching and learning worldwide.

Technology-enhanced learning or digital learning encompasses a wide variety of learning models, digital technologies and services. In essence, an academic staff engages digitally with a student in the context of a pedagogic framework and the outcomes are monitored and measured using an assessment strategy. The use of digital tools to enhance and support learning can occur before, during or after teaching and learning sessions, and support a variety of pedagogic interventions.

Overall, the chapter presents in a nutshell, the challenges brought by digital work and the need for digital transformation and interventions to overcome those challenges.

2 Challenges in the Education Landscape: The Challenge of Disparities, Inequality and Exclusion

There is much interest in information technology in various higher education institutions in South Africa because of the information age that started in 2000. Information and communications technology (ICT) became a basic requirement in higher education institutions in South Africa as a facilitator of knowledge creation and communication yet it was not policy and finance-driven. Although higher education institutions spent more money on ICT infrastructure, the infrastructure is poor and unsustainable (Johl, von Solms and Flowerday 2013:628). The academic staff have no option but to depend on the ICT infrastructure to ease teaching and learning in the classroom and it needs to improve to sustain the academic project (i.e. achieving graduateness as a throughput derived from the student lifecycle) uninterrupted with high and reliable bandwidth connectivity.

The South African higher education landscape is partially transformed and not ready to possess the required skills for the twenty-first century digital society. The critical skills to be in possession by an academic staff required here in the digital education space include business intelligence, digital transformation, cybersecurity, and cloud computing to transform the education landscape at work by consistently and constantly influencing learning, teaching and research applications.

However, the academic staff are not equipped enough to respond swiftly to changing the workplace's digital demands (Yende 2021:58). Understandably, about 24% of the population in Africa has access to stable internet connectivity and this accounts for digital disparities which are problematic to sustaining teaching and learning. Economic hardships and socio-economic imbalances made it difficult for the students to access online education due to the exorbitant costs of data required for online education and intermittent power cuts commonly referred to as load shading in South Africa (Simbarashe 2021:288). The rural-based institutions or the so-called historically disadvantaged institutions are the hardest hit as they absorb a large volume of students from disadvantaged families.

In the historically disadvantaged institutions previously referred to such as the University of Venda, University of Fort Hare, University of Limpopo, Walter Sisulu University and North-West University among others, there was resistance to adopting technology because it was not affordable to advance teaching and learning while privileged universities like University of Cape Town, Stellenbosch University and the University of Pretoria reached out to funders to enjoy high tech digital environment in their educational spaces. This is despite the attempts by the government to bridge the digital divide. One of the major reasons is that historically disadvantaged or rural-based universities in South Africa are the ones that were historically disadvantaged by the Apartheid rules and predominantly pushed to the fringes and struggle to attract qualified academic staff hence they experience staff turnovers and shortages (Simbarashe 2021:292,296).

Although the education sector welcomed the application of digital technologies to access education globally, it looks like academic staff in South Africa are caught napping and are still not well prepared or do not feel confident to teach in a digital environment because of their inadequate skills capacities and competencies to interact with the digital teaching and learning platforms. There is no dedicated programme or curriculum to advance their knowledge in the use of online technologies. The workplace is also not ready and still uses old enablers of teaching and learning in specific universities. Out of South Africa's 413 067 academic staff, only 132 884 had been officially trained in basic ICT utilities in 2014. In 2022, better still, not all academic staff have adequate online teaching competencies and experiences. It is a result of the lack of curriculum for staff development and the use of obsolete equipment at the workplace in several South African universities (Masenya 2021:11, 12).

In one historically disadvantaged higher education institution in Limpopo province, the study underlined that most academic staff members are products of rural-based institutions and are stereotypically resistant to change. They did not go through rigorous technical training and heavily relied on physical classes. Before Covid-19, academic staff would refuse students to submit assignments via an online platform and preferred typed and printed hardcopies, which was an expensive and time-consuming effort. The academic staff struggled to utilise digital learning applications making it difficult for the students to learn (Mawere, Mukonza and Kugara 2021:57, 58). This perpetuated a high failure rate because of many ‘at risk’ students and modules.

The academic staff must accept that the world has transitioned into the digital age in which the use of technologies dominates every facet of our lives including access to education. Confronted with this reality, most higher education institutions in South Africa, especially rurally based universities, must expose academic staff to change from the old conservative ways of offering education in the classroom. The academic staff across the education sector are under the immense pressure of using digital technologies to enhance teaching and learning but they are inadequately skilled and experienced. Academic staff should tap into the digital revolution and adopt new technologies and methods to improve their teaching practices and thereby benefit their students. However, for this to change, it requires a targeted curriculum and learning opportunities in continuing higher education to help employees to better cope with the challenges of digitalization in their work environments.

As such, the historical didactic methods of transmitting academic knowledge from the academic staff to the student must be uprooted to pave a way for digital interventions and adaptations. For this to happen, the adaptation requires the academic staff to possess the requisite skills and abilities to cope with the digital age (Masenya 2021:2). Academic staff are concerned more about the future of their careers and fear substitution by artificial intelligence. One of the main concerns is that the blending of digital technology into the education system blurred the lines between in-person and digital teaching (Yende 2021:64, 66).

Hitherto, the recipient of education is the victim of this unequal education. The Covid-19 pandemic made it worse to exacerbate these inequalities, which require digital transformation across the education landscape to ensure equal access. Ohei and Brink (2019:2) confirm that higher education institutions in South Africa are exposed to many vulnerabilities, including teaching and learning, which require special attention. Consequently, the level of high unemployment especially for unemployed graduates is telling the story about the quality of education, access to the job market and skills exposure. According to Yende (2021:61), the high rate of unemployed graduates and the lack of proper skills required in the labour market is a cause for concern. It is because, largely, the South African higher education institutions are currently overwhelmed and overstretched with student capacities beyond their limits to cater despite severe infrastructure and staff capacity shortages and inadequate digital skills. The previously disadvantaged universities are the most affected (Krishnannair and Krishnannair 2021:76, 77).

The main challenge of the digital transformation of the education sector that is switching to online learning is the problem of inequality in South Africa. South Africa is the most unequal country in the world as shown by Zikhali (2018) in one of the World

Bank Group (WBG) reports. It was highlighted that the top 1% of South Africans own 70.9% of the country's wealth while the bottom 60% only controls 7% of the country's assets (WBG 2018; Zikhali 2018). Introducing 4IR in an unequal society in Africa like South Africa has the risk that only the wealthy will have access to the new technological developments for educational purposes leaving the poor behind.

Kayembe and Nel (2019) indicate that inequality was clearly shown with the implementation of the other three industrial revolutions. Up to now, a large proportion of the population still lives without transport, electricity, and the internet. As a result, the gap between the "haves" and "have nots" creates further alienation, lack of trust, and social unrest (Kayembe and Nel 2019). In South Africa, some universities can easily integrate online learning with minimal challenges. For example, the University of Johannesburg has been integrating 4IR in learning even before Covid-19 and found it easy to switch to the 4IR type of learning. However, other rurally based universities find it hard to integrate online learning due to challenges related to resources and skill capacities. These universities struggle to catch up with other universities lagging because of widespread inequality in the education sector (Mhlanga and Moloi 2020b).

In South Africa, access to technology especially internet connectivity is unequal and limited (Meyer and Gent 2016; Kayembe and Nel 2019). Some groups in South Africa, especially institutions of learning in remote areas, have poor access to the internet and in some instances, they do not have electricity. Digital transformation of the education sector implies that these groups continue to be marginalized. During the Covid-19 pandemic, various 4IR tools were introduced as a stop-gap measure to counter the negative effects of Covid-19 and lockdown restrictions on the academic year. Students in towns and cities were able to access learning through various platforms, which include virtual classes offered by the South African Broadcasting Corporation in partnership with the government.

Some students learned through cloud online lessons, while others accessed learning through the department of education website and zero-rated mobile apps among many platforms. These various initiatives were put in place to mitigate the disruptions brought by Covid-19 while other platforms were already present before the pandemic. However, students in remote areas were unable to have access to online learning because some do not have access to radios and television, while others do not have access to electricity and internet connection. In a way, these students are being summarily excluded from accessing basic human rights such as access to education. Kayembe and Nel (2019) argue that the gross participation rate of black Africans in education is lower than their white counterparts. Many black South African students have problems with enrolment in mainstream education. The introduction of online learning exacerbated the exclusion of black Africans from education (Xing and Marwala 2018).

Another big challenge that perpetuates inequality and exclusion in the education sector is limited funding (Kayembe and Nel 2019; Xing and Marwala 2018). Over the years, funding in the education sector has been increasing but the budget is not sufficient to fully fund full online instruction with a full online presence (Kayembe and Nel 2019; Mayer 2014). Apart from the inadequacy of the education budget, the national government spent a lot of money fighting the Covid-19 pandemic (Government of South Africa 2020). The available budget to fund the programme such as paying for internet subscriptions, data, and buying laptops for students and instructors is not sustainable, especially for historically disadvantaged universities. Universities should invest more in new technological advancements and a variety of technical infrastructure as well as the training of instructors.

Brown-Martin (2017) writes that one of the biggest costs of the digital transformation of education is the investment in sophisticated technological infrastructure. Well-funded, well-managed ICT academic environment as the foundation to offer support for teaching and learning with technology is crucial. There is a need to have a pool of on-site support to remotely offer technical advice to academic staff and students but all these require funding for infrastructure and capacity development of academic staff, which must be prioritised.

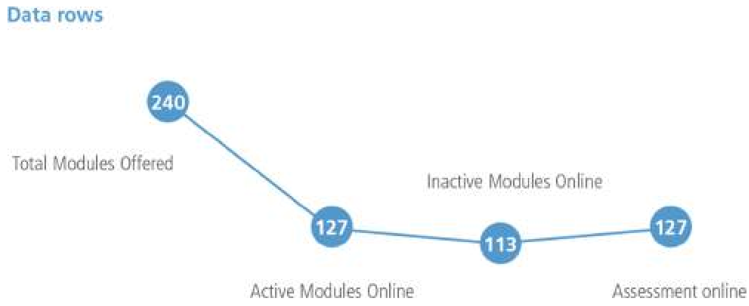
3 A Switch to Online Teaching and Learning

The lockdown realities of Covid-19 have forced South African higher education institutions to switch to online teaching and learning. South African universities are no exception. For instance, in 2020, the University of Cape Town, the University of Johannesburg and the University of Pretoria told students that online teaching and learning is compulsory in the second semester (Universities South Africa 2020). These universities saw the rapid change as the start of the process that disrupted and shifted the education landscape to that of the 4IR in which learning takes place digitally with a few occasions of in-person engagements. Universities conducted teaching and learning using Blackboard, Moodle, Microsoft Teams, and other applications. This of course came with challenges as some academic staff were exposed to online platforms they did not interact with before.

After engaging with a university policy in one South African university, mandatory e-learning online presence is crucial for teaching and learning to take place effectively. A minimum online presence is required for all modules and this includes assessments (tests and assignments), collaboration (activities where students interact with other students – working in groups or projects), communication (activities such as announcements sent through emails and social media handle such as WhatsApp to staff and students through an integrated ICT system), content (study materials such as notes, slides, and videos made available for teaching and learning), site management (working on all accessible modules allocated online) and user management (all general aspects involving a module owner allocating module tasks to users, viewing them, or categorising them for user-friendly access) (E-Learning Policy and Procedure 2021:4). Despite these policy imperatives, the minimum online presence was compromised by most academic staff as seen in Table 1.

Table 1 reflects the online presence of University X. University X is one of the twenty-six universities in South Africa established in 1982, about 40 years ago which is historically disadvantaged. It largely enrolls students from historically disadvantaged communities. From Table 1, online presence reflects the following features: (a) total modules offered (240), (b) active modules online (127), (c) inactive modules (113) and (d) assessment online (127). In this case, 127 active modules online mean that the academic staff uploaded documents online usually the learning guide, lecture notes, assignments etc., and actively used online applications such as Moodle throughout the semester to engage and liaise with the students whereas 113 inactive modules online

Table 1. Minimum Online Presence (own illustration)



simply meant that there was no activity online not even uploading of learning guides, lecture notes or assignments by the academic staff.

Meeting minimum online presence requires well-developed learning, enhanced, and supported with digital tools. This way, it can enhance the student experience, potentially improve student outcomes, widen participation, and improve accessibility and inclusion (Janet 2010: 27–35). There are however also risks associated with adding a digital element to learning that could result in challenges due to reconciling the inconsistent experience resulting from the differences between the physical and digital student experience such as the impact on connectivity and bandwidth, technology displacing effective practice, poor experience due to insufficient skills and capabilities across staff and students (Badat 2010: 17–21).

There are a lot of technologies available for online teaching and learning processes but sometimes they create constraints. Some examples of technical issues are errors in downloading material, installation issues, login, audio and video problems (Dhawan 2020). Besides, modules taught online posed challenges to the academic staff as they are feeling alienated, experienced low self-esteem and consequently pressurised to increase their self-learning abilities (Dyment and Downing 2018). Dyment and Downing (2018) argue that the academic staff also feel overwhelmed when using technology and thus become insecure in attaining their intended targeted teaching objectives.

As far as technology is concerned, Orlando and Attard (2015:119) state that teaching using technology is not a one size fits all engagement because it relies on the types of technology used at a given point in time and the content of the curriculum that is being taught. Arguably, the infusion of technology presents value propositions to be considered in line with teaching pedagogy and learning experiences. Kirkwood and Price 2014:6) contend that it is often taken lightly that technologies enhance teaching and learning. Presumably, technological infusion, enhancement of learning and engagement of students are inextricably and mutually connected. However, in creating individually tailored differentiated instruction for each student within and across each cohort, additional workload pressures on those seeking to engage with the online environment can be created as academic staff seek to respond often reactively to the individual learning and engagement needs of each cohort.

The other serious challenge is an absence of a clear integrated national strategy. The fact that the disruptions in education came at a time the national government is preoccupied with the fight against Covid-19, made the process of adopting synchronous online learning lack the support of the national government and even the provincial government (Mhlanga and Moloi 2020a). Where the support is available, it differs from one province to the other. For example, although a kind of collaboration can be deduced from the announcements given, each university is autonomous (Johannesburg 2019). This in a way creates disparities in terms of access across universities in the country (Oke and Fernandes 2020).

One more big issue is the lack of uniformity across universities and the response to Covid-19 in the education sector, which did not have a consolidated national government front. It is because various role players did respond, sometimes in a fragmented manner without targeting the student community. In this case, students in rural areas were left out of the programmes introduced since they were targeting students with access to the internet and computers (Mhlanga and Moloi 2020b).

The absence of integrated strategic direction from the government made the digital transformation of education difficult. Generally, academic staff fear the uptake of ICT more than the students and are not exposed to digital work interventions. So, digital work interventions should be communicated with much clarity of thought to empower the academic staff as they have distinct levels of knowledge. Consequently, clear institutional programmes should be put in place because there are numerous benefits to students exposed to online teaching and learning on ICT platforms. The academic staff must prioritise offering modules online using proper and user-friendly online teaching and learning tools. As such, clear goals must be set to intentionally train academic staff and students to successfully switch to online teaching and learning (Meyer and Gent, 2016; Kayembe and Nel 2019).

4 Some Technological Interventions, Applications and Adaptation

Most historically advantaged and disadvantaged universities resorted to digital platforms such as Zoom, Microsoft Teams, Moodle and Blackboard to increase teaching and learning during and post-Covid-19 periods as a stop-gap measure but this is proving to be a permanent solution to match developing countries with those of the developed first-world. It requires the power of humanity to invent and adopt digital solutions through research and innovation irrespective of their circumstances and this calls for rural-based universities in South Africa to pledge solidarities and partnerships with advanced institutions and private bodies to find suitable technologies to support hybrid (in-person and online) teaching and learning (Simbarashe 2021:295–6). Simbarashe (2021:297) argues that hybrid teaching and learning require adequate capacitated academic staff to enable efficient digital use without compromising access and the quality of education. It is also crucial for rural-based institutions to adopt simple, accessible, and efficient technologies rather than ambitiously attempting sophisticated technologies that are used in elite universities.

There is a need to target levelling the education landscape by prioritising the transformation of the infrastructure in line with digital teaching and learning demands. Classrooms must be transformed and equipped with user-friendly technology that is compatible with the use of various gadgets such as laptops, smartphones, and tablets, to enhance hybrid teaching and learning. There is no longer a need to invest more in physical learning structures but in teaching and learning devices, connectivity and bandwidth and it requires intentional capacity development of the academic staff to optimally make use of these technologies. A radical shift and transformation of the education landscape are crucial in the quest for a permanent digital solution. Apart from staff capacity development, e-learning policies, online staff management and monitoring tools to ensure learning efficiencies and quality education are equally essential (Simbarashe 2021:298).

The transformation of the education landscape requires resourced digital librarians equipped with library websites integrated into the learning management system with quick links to plagiarism prevention and referencing software, reference guides, and free software downloads used for accessing electronic resources such as videos and soundbites via single sign-on authentication on the official library webpage (van Wyk and Kadzenga 2019:52,58). Digital learning is an opportunity to rethink the way we design and deliver university modules and how libraries are stacked with electronic resources. Many universities aim to provide parity of experience to all students, whether they study online or in person, locally or from abroad. Students, in turn, reciprocally benefit from a greater choice of pace and place of learning in the classroom and the library's online settings. Loaning learning material from across the twenty-six South African universities without boundaries and hassle is a huge win and intervention in the transformation and integration of the education sector.

The wide adoption of digital learning means that our ideas of what it means to belong to a university community will need to be reconsidered. Personalised and proactive, digital learning could help build and nurture lifelong relationships for both academic staff and students, but they will also need support to develop the digital skills, confidence and resilience required to succeed in the digital space as opposed to physical settings. Effective use of digital technology is seen as fundamental in helping to ensure continuity of teaching and learning, meeting current and future social distancing requirements, and engaging positively with students. The higher education landscape has changed and continues to metamorphose. Consequently, existing models of learning may not be appropriate or practical. Universities must reflect not just on how blended or hybrid teaching and learning can be optimally used to deliver modules, but how existing curriculum models will need to be adjusted to fit the new normal.

It is tempting when discussing technology-enhanced learning to focus on the digital technology element, not least because of the cost and challenge of learning how to use it. However, we are clear that the pedagogic considerations are vastly more important. All successful education and training require close attention to learning design and content creation, and technology-enhanced learning is no exception. The successful implementation of online learning is the availability of appropriate skills and resources for students, academics and support staff. According to Butler-Adam (2018) appropriate skills are required for the full implementation and proper management of the technology associated with online teaching and learning. Appropriate skills are important so that the education sector could benefit meaningfully from digital technologies (Kayembe and Nel 2019). Also, the use of instruction requires coordinated guidelines across the education sector so that there is a provision of a theoretical foundation for digital pedagogy (Kayembe and Nel 2019; Xing and Marwala 2018).

Östlund (2008), Ekstrand (2013), Meyer and Gent (2016) and Kayembe and Ne (2019) write that academic staff are required to learn technology integration strategies and to support students with various needs to maximise online presence. Academic staff and instructors need to appreciate the role of ICT in education policy, curriculum, and assessment as well as the organisation and administration of education. Collaboration mechanisms should be in place and instructors must have ways of sharing information as it allows them to take ownership and optimal use of the technology. Training and awareness are required to ensure that ICTs are integrated with the support of pedagogy, in a phased manner. There must be clear goals established to guide academic staff and their students in using ICTs in support of teaching and learning. A large pool of e-skilled academic workforce should be available to improve the quality of education.

In the main, the introduction of the Department of Higher Education and Training (DHET) Staffing South Africa's Universities Framework – a Transformative, Comprehensive Approach to Building Capacity and Developing Future Generations of Academics (SSAUF), the New Generation of Academics Programme (nGAP) meant to prepare and absorb postgraduate students in the workplace to develop teaching and research abilities ready to take permanent academic positions in the universities, the University Capacity Development Programme (UCDP) and the University Capacity Development Grant (UCDG) structured around student and staff development, as well as curriculum transformation and programme development, are critical drivers of digital transformation. The unleashing of these four interventions among others in the education sector – i.e. the SSAUF (2015), nGAP (2015), the UCDP (2017) and the UCDG (2017) go a long way to improve the capacity of academic staff and students to be readily prepared to adapt to universities digital workplaces conducive to teaching and learning. However, the success of these four interventions requires an integrated national effort across the twenty-six universities in South Africa to digitally work effortlessly and impeccably.

5 Conclusion

The sudden change in how education is delivered due to the Covid-19 pandemic and the 4iR has impacted both students and academic staff in many ways possible. Adaptation and changes are unavoidable in the new normal as the chances of reverting or reversing to the old normal are practically impossible. Abiding by the DHET recommendation to move educational activities to a virtual teaching model using the existing institutional software and available public digital platforms, has its issues and challenges.

From the ensuing discussion, students faced many challenges related to connectivity, network and bandwidth limitation, affordability of data, inadequate class interaction and emotional trouble. Likewise, academic staff faced the same problems when conducting classes on the digital platform with a minimum online presence. The topmost concerns that challenged academic staff are related to the accessibility of network and bandwidth, low self-esteem and capacity adaptations to class interactions with a minimum online presence.

Hence, it is essential to find practical ways and digital solutions to improve the quality of online teaching and learning at the university workplace. With the information and benchmarking of better teaching and learning best practices for 21st-century, students and the academic staff must be skilled to become technologically savvy and empowered to choose and utilise effective tools, innovative techniques such as chatGPT, Grammarly etc and interactive approaches for student-centred learning, while the university management should provide a conducive and stable platform for online teaching and learning environment using the four interventions among others – SSAUF, UCDP, UCDG and the nGAP adaptable across the twenty-six universities in South Africa.

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It's Coming Home Down Under – The Potential of Digital Work to Overcome Australia's Challenges in Reshoring Manufacturing

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Abstract. Over the past decades, the world has seen a continuous increase of globalisation and interconnectedness – in part supported by advances in digital communication and production technologies. In the case of industrial production, this trend has led to global, integrated supply chains in order to provide the most competitive and innovative products utilising the most competitive market conditions. In Australia, due to its remote geographic location and socioeconomic conditions, such as high labour costs and negative economics of scale, this has resulted in a loss of domestic manufacturing capabilities. With recent changes in the geopolitical environment (trade wars, actual wars, Covid-19, climate crisis etc.) calls to produce local are becoming louder again. In this article, we therefore explore the potential of digital technologies to overcome Australia's challenges in reshoring its manufacturing capabilities. Findings indicate that a highly skilled digital workforce is needed to leverage the country's potential in world-leading niche manufacturing. The Associate Degree of Advanced Manufacturing, developed and delivered by the Centre for Advanced Manufacturing at the University of Technology Sydney (UTS), is presented as an example of how to upskill the manufacturing workforce.

Keywords: Industry4.0 · Reshoring · Advanced manufacturing · Australia · University degree

1 The Tides Are Turning – From Offshoring to Reshoring

1.1 The Move to Globalisation and Integrated Supply Chains

Over the past decades, the world has seen a continuous increase of globalisation and interconnectedness – ranging from digital communication technology via cheap and fast travel to continent-spanning industrial production and supply chains. This led to a trend towards globally integrated supply chains, where high-wage countries are competing with low-wage ones in a highly competitive international environment. As a result, many high-wage countries, including Australia, outsourced parts of or often their entire production to offshore sites or suppliers (Adler and Breznitz 2020).

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1.2 Australia's Role

This trend was amplified in remote countries with small domestic markets, such as Australia. Importing became cheaper than local manufacturing, despite the long shipping distances. Especially in Australia, this has led to a severe loss of general manufacturing capabilities. A prominent case was the last Australian automotive manufacturer, GM Holden, to close down its production facilities and leave the country in 2020. While capabilities around commodities such as mining and agriculture are strong in the Australian economy, manufacturing capabilities are limited. As a consequence, Australia has a very low economic complexity compared to other countries of similar wealth (Wyeth 2022).

1.3 The World is Changing Again

In recent times, the world has started to change again. One of the most prominent challenges of global manufacturing and collaboration has been Covid-19. Lockdowns around the world have impacted all industries. Examples are the challenges in the distribution of surgical masks, or the shortage of microchips, jeopardising products from computers to cars and leading to increased prices and delivery times (Wu et al. 2021). In parallel, lockdowns in central container terminals have led to massive shipping delays and a heterogeneous geographic distribution of empty containers, further complicating logistics (Sheffi 2021). In addition, the ongoing trade war between Australia and China as well as new military conflicts, such as the Russian invasion of Ukraine, have further disrupted global supply chains. In parallel, a continuously growing awareness of sustainability has brought the reduction of e. g. energy consumption and CO_2 emission of logistics into public and government focus. More product-oriented trends include a growing demand for customised products that might even be adapted after an order was placed, which becomes more difficult with increasing shipping times (Kuhl and Krause 2019).

1.4 A Rethink Towards Reshoring

The resulting pressure on and uncertainties around global supply chains have led many to rethink the benefits of offshore manufacturing (Adler and Breznitz 2020). This has triggered increased attention to a counter-movement called "reshoring". It comprises both, "backshoring" into the original country and "nearshoring" to a nearby often neighbouring country (Éltető 2019). This does not necessarily mean a complete departure from the offshore manufacturing country and de-globalisation, but a strategic relocation (Éltető 2019). This trend has been supported by governments around the world. In line with the European Economic and Social Committee that sees reshoring as the foundation of re-industrialising the European Union, the Australian Government has launched several initiatives to drive local manufacturing, such as "Australian Made" and "Buy Local", as well as a general push for national sovereignty to overcome the current lack of qualified welders and other workers (Australian Government 2016; Crittenden 2022). In parallel, the political change towards reducing climate change is reflected in the industry. As an example, the mining mogul Andrew Forrest has committed to building 5.4 GWs of solar and wind energy capacity in the Pilbara region in Western Australia including the plan of building a much larger site for substituting fossil energy sources through the onshore production of green hydrogen in the Nullarbor Plain in South Australia (Milne 2022; Waterworth 2021).

1.5 Effects on Australian Manufacturing

Having moved away from manufacturing and towards a service-led economy over the past decades, reshoring poses a significant challenge to the Australian economy. Instead of pursuing mass manufacturing and global exports, a more viable path for Australia might be to focus on the manufacturing of customised quality products. Instead of global supply chains, global production networks based on digital data and knowledge can enable the export of Australian designs. An example is the joint Smart Global Brewery Network of the University of Technology Sydney in Australia and the Technical University of Dortmund in Germany, which allows to develop beer recipes that can be created on one brewery system, then transferred and automatically produce beer with the same quality on the other brewing system (itnews 2022).

1.6 Technology Enablers

To enable these use cases, digital technologies are required, which can range from CAD models for additive manufacturing via smart cobot controls to cyber-physical systems that combine the physical and the virtual worlds. Due to their complexity, these technologies and manufacturing systems cannot be developed in isolation, but need an interdisciplinary team of experts. This is not limited to system developers, but also includes its users, who need the expertise and skills to successfully install and use these systems. While skilled staff is reported as a key success factor of digitalisation and reshoring, they represent a key bottleneck at the moment (Adler and Breznitz 2020). Moving from manual to automated manufacturing activities, staff often needs completely new skills (an example being welders now programming welding robots rather than welding themselves). As technologies are usually not used in isolation, but as part of a bigger solution integrating different technologies, a diverse set of expertise is needed. This ranges from profound knowledge of basics, such as mathematical or engineering mechanics, programming and robotics as well as new collaboration and managerial skills to work in interdisciplinary teams.

Against this backdrop, the question addressed in this study is how to digitally enable Australia to successfully tackle its reshoring ambitions. For this purpose, Sect. 2 uses a literature review to analyse the potential of digital technologies as an enabler for reshoring. Section 3 focuses on the specific reshoring situation in Australia, and how necessary digital expertise and skills could be built in the workforce. Section 4 concludes this study with implications beyond the Australian context and provides an outlook on the near- to medium-term future.

2 Digital Technologies to the Rescue – Are They a Game Changer for Reshoring

2.1 The Emergence of Digital Capabilities

While the trend towards reshoring of manufacturing is driven by external factors such as increased supply chain costs and uncertainties, there are technological drivers that allow to reduce manufacturing costs to a competitive level. This specifically includes digital, often called Industry 4.0 (I4.0), technologies, enabling advanced manufacturing and robotisation, which can be used to substitute expensive labour activities (Éltető 2019).

Digitalisation is becoming a decisive competitive factor, presenting engineers and technicians with new challenges as innovations and new business models emerge at the interfaces between traditional engineering disciplines. For industrial production and engineering, I4.0 is transforming manufacturing throughout the world by bringing real-time data, automation, data analytics and intelligence to operations. The I4.0 era is defined by an exceptional technology push around automation and digitalisation (Lasi et al. 2014). Technologies applied under the umbrella of I4.0, such as additive manufacturing, digital automation, big data, or cloud services are shaping modern manufacturing operations and contribute to performance improvements (Dalenogare et al. 2018). Industry 4.0 has been spreading across the world in all industrial sectors, from mining to food.

So can digital technologies support a movement to bring home manufacturing jobs? As enabler for solving complex problems across global supply chains and production, digital technologies can play a role (Treven 2022). There is, however, an argument that the digitalisation of manufacturing could lead to both stronger geographical integration and fragmentation and that any specific effects will emerge in a sector-specific manner (Butollo 2021). Others question the causalities between backshoring movements and I4.0 technology adoption altogether (Kamp and Gibaja 2021). In the following, current literature is reviewed to clarify if and how I4.0 could help with reshoring ambitions.

2.2 Does I4.0 Help with Reshoring Ambitions?

The search term developed by Fratocchi and Di Stefano (2020) was used in Web of Science to identify the relevant literature on reshoring in general: "reshor*" OR "re-shor*" OR "backshore*" OR "back-shor*" OR "back-reshor*" OR "back-sourc*". We find that research output on reshoring has steadily grown over the last 20 years, with a very prominent uptick in 2016 (see Fig. 1). This trend started even before recent geopolitical shifts (such as Covid-19) might have further accelerated this.

But what about research at the intersection of reshoring and digital technologies? To analyse the cross-section of these two areas, we added a search string relevant to digital production and I4.0 following Moeuf et al. (2018) and, to widen the search, added technology as an additional term: ("reshor*" OR "re-shor*" OR "backshore*" OR "back-shor*" OR "back-reshor*" OR "back-sourc*") AND ("Industry 4.0" OR "Digital production" OR "Digital manufacturing" OR "Internet of things" OR "Cyber Physical System" OR "Cyber Factory" OR "technology").

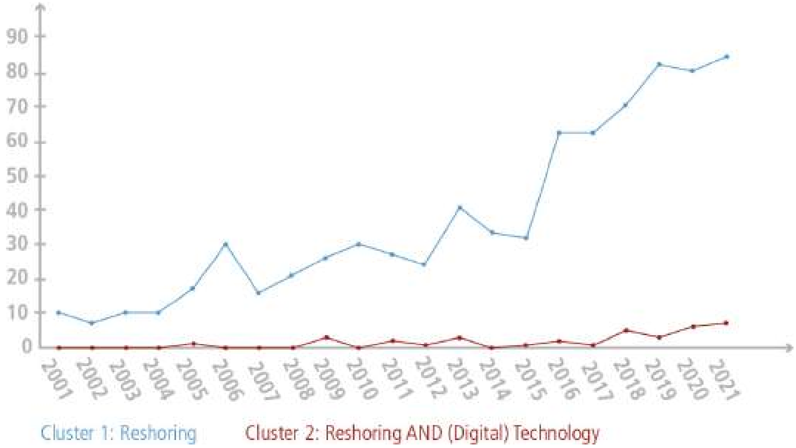

Fig. 1. Publication numbers over time (according to web of science).

It can be observed that research on digital technologies as an enabler for reshoring ambitions is still emerging (see Fig. 1). While empirical research at this cross-section is rare, some recent studies have highlighted the potential of digital work and technologies for successful reshoring ambitions.

In high-cost countries in the Americas and Europe, there is a persistent focus on cost reduction, which led to initial offshoring initiatives and now remains a core reason for reshoring. The limited adoption of new technologies does not seem to change that focus (Ancarani and Di Mauro 2018). At the same time, I4.0 technology is most likely adopted by highly innovative firms competing on quality (Ancarani et al. 2019). As key enablers for cost-effective reshoring, digital technologies have some way to go. In the context of Denmark, the perceived relevance of I4.0 technologies has a high impact on companies that have moved manufacturing back compared to companies that have moved manufacturing out. "The objective of Industry 4.0 in Denmark is to bring manufacturing home or remain domestic" (Stentoft and Rajkumar 2020). In Germany, however, I4.0 seems to remain of lower importance regarding corporate reshoring ambitions (Müller et al. 2017).

So how, specifically, can digital technologies under the I4.0 umbrella contribute to reshoring ambitions? Enabling the manufacturing of High-Mix Low-Volume (HMLV) products is a strength of I4.0 and its pool of digital technologies (Johansen et al. 2021). This allows companies and countries with a low level of automation to quasi-skip Industry 3.0 and directly set up a state-of-the-art manufacturing system. In this respect, technologies like additive manufacturing ("3D printing") allow for complex custom-made designs that can be flexibly post-processed and combined with other products using intelligent robots, such as collaborative robots ("cobots") (Mehrpouya et al. 2019). Additive manufacturing has also been found to play a contributing role through enabling shorter lead-times, lower transportation costs and inventories, more customisation options, fewer supplier miscommunications and increased responsiveness to product and market changes (Moradlou and Tate 2018). The Internet of Things can further support the creation of smart, flexible and transparent domestic supply chains (Ghadge et al. 2020). These can help with predicting process bottlenecks as well as showing customers the origin of all product resources.

So how can the implications of these new I4.0 technologies on Australian manufacturing workplaces and workers be assessed and possibly serve as an enabler for reshoring and reindustrialisation? Australia, being a geographically remote country with high labour costs, could benefit from those technologies in unique ways.

3 The Australian Case – Building a Digital Foundation to Bring Back Manufacturing

3.1 The Unique Manufacturing Landscape in Australia

Dean and Spoehr (2018) provide a comprehensive analysis of Australia's set of manufacturing challenges and opportunities arising from the fourth industrial revolution. Some key findings are that:

- "little attention has been paid to the social and economic implications of Industry 4.0 for Australian workplaces, workers and society – specifically in the context of manufacturing",
- "insufficient attention has been paid to the importance of building Industry 4.0 technological and organisational capability and capacity amongst manufacturing SMEs and preparing larger firms for digital transformation",
- "Australia lags behind many of its competitor nations in the adoption and diffusion of advanced technologies and skills", and
- "given Australia's relatively low economic complexity, there is a risk that a lack of collaboratively determined policy for Industry 4.0-driven industrial transformation leaves Australia insufficiently prepared to take full advantage of the opportunities flowing from Industry 4.0."

3.2 New Skills Are Needed

In light of these challenges, organisations need to close existing knowledge gaps within their business domains in order to leverage opportunities emerging from digital technologies. According to the Australia Institute's Centre for Future Work, "the reorientation of manufacturing production around more specialised and skills-intensive production strategies reinforces the need for more highly trained and technology-capable manufacturing workers" (Stanford 2020). Hence, the Australian Government Department of Education and others have identified an urgent need for training in this area as a part of the Australian Government's Job-ready Graduate Package (2021). To bolster manufacturing expertise and capabilities domestically, the Department of Education sponsors the advanced apprenticeship-style Digital Technologies (Industry 4.0) pilot at six Australian universities (Tehan 2020). This includes funding for the development of the program plus substantial tuition fees for up to 20 students as a pilot cohort. Students need to be employed by local small or medium-sized businesses. Another requirement for students to enrol in this program is commitment from their employer to the study required, e.g. through flexible working arrangements.

3.3 A New Degree

The University of Technology Sydney (UTS) participates in this program by creating and delivering the Associate Degree of Advanced Manufacturing (ADAM) (UTS 2021). ADAM is a 2-year degree if undertaken full-time and aiming at.

- boosting the capability of local value chains and strengthening university-industry collaboration in teaching and research,
- embedding industry partnerships with participating universities, deepening links with local businesses, encouraging the culture of collaboration between higher education and industry, and.
- delivering additional higher-level technical skills that directly articulate into a Bachelor's degree on completion if desired.

To bring the latest research directly into the classroom, the UTS Centre for Advanced Manufacturing (CAM) leads curriculum development and course design for ADAM (UTS 2021). The ADAM curriculum is designed around four streams, representing the interdisciplinary nature and unique combination of future skills needed to bring advanced manufacturing to the workplace: Industrial and Manufacturing Engineering, Data Management and Analysis, Automation and Robotics and Complex Systems Management.

Within these streams, a range of new courses has been specifically designed for ADAM. For instance, the stream Industrial and Manufacturing Engineering includes the course Production System Design to introduce lean manufacturing as a prerequisite for digitalisation and the course Factory Modelling and Simulation to familiarise students with digital twinning. Data Management and Analysis builds on the Industrial Internet of Things Studio as well as Machine Learning and Industrial Data Science. Automation and Robotics has a focus on collaborative robots, e.g. via the Collaborative Robotics Studio, where students get to experience advantages and limitations of the technology as well as use cases in different domains. Complex Systems Management includes e.g. Product Development for Industry 4.0, where students apply product development methodologies to systematically develop new technical products in the advanced manufacturing context.

The courses focus on providing students with the skills and tools required to apply advanced manufacturing in their workplaces. While all courses are project-based, a number of courses are offered in a studio environment, taking hands-on and applied learning to an advanced level. The equipment provided by our industry partners helps in providing the latest technology and hardware used by leading firms in the advanced manufacturing arena such as Balluff, Bosch, and Siemens. Assessments are designed in a way that students' workplaces can serve as a case study for current state analyses and, more importantly, improvement and optimisation. Exams play a minor role, the focus is on demonstrations, reports and presentations, individually and in groups. This allows immediate translation of learnings to the workplace.

ADAM is making a start to tackle Australia's challenges in using I4.0 technologies to reshore manufacturing. The new degree develops technological and organisational I4.0 capabilities for SMEs based on a state-of-the-art curriculum targeted at upskilling the manufacturing workforce. Critical to success was the UTS CAM global partner network. In addition to Australian companies from the manufacturing sector, we have particularly involved German companies that are both lead providers and lead users of Industry 4.0 technology. Since industrial data science plays a significant role in the context of advanced manufacturing, our corporate partners have been selected accordingly. In addition, we have involved Australian national and German industry associations representing a large number of SMEs. Social and economic implications have also been included, e.g. via the Complex Systems Management stream or built-in into other courses such as safely introducing collaborative robots into the workplace, taking into consideration not only physical but also psychological and ethical risks (Guertler, forthcoming).

4 Conclusion

The authors of this paper have no doubt that the availability of academics well-trained in STEM subjects will be a key factor in the competitiveness of manufacturing industries worldwide. However, a highly skilled workforce alone will not help Australia achieve a manufacturing renaissance. The development of global supply chains, which is difficult to predict, will be decisive in determining whether manufacturing in Australia will once again be more strongly geared towards the local market. Current and future global crises, but also the need to drastically reduce CO_2 emissions, could have a positive impact on the competitiveness of Australian factories in the local market. However, it is very likely that Australia will not become an export country for industrial goods based on the German model due to its geopolitical situation, geographic location and the high labour costs in global comparison. Therefore, Australia must also find its own way with regard to the digitalisation of the manufacturing industry and cannot simply copy approaches from leading industrial nations.

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Digital Work in East Asia

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Abstract. Recent developments and the actual status regarding Digital Work are described for the East Asia/Pacific region, based on data and analyses available for the region. This includes aspects like decent work, the effects of digital technologies on tasks, competences, labor market opportunities, the effects of digital work and labor platforms, and issues of gender (in)equality. Challenges and political actions taken by national governments are described by looking at the example of Taiwan, one of the most advanced economies in East Asia and worldwide.

Keywords: Digital work · Working conditions in East Asia · Digital capacities and talents · Digital work and labor platforms · Taiwan

1 Introduction and Background

1.1 Decent Work in the Asia-Pacific Region

In their Asia–Pacific Employment and Social Outlook 2020, the International Labour Organization (ILO) describes the impact of the COVID-19 pandemic with respect to the, as they perceive it, weak foundations of decent work and inclusive growth in many Asia-Pacific economies (ILO 2020). Even before the pandemic, employment growth did not keep pace with general economic growth in the region, and labor income shares stagnated or decreased. Only in East Asia, where most of the advanced economies of the Asia-Pacific region are located, the average annual labor income share grew marginally in the period between 2011–17. In the other subregions – South-East Asia, South Asia, and Pacific Islands –, labor income shares fell in that period (ILO 2020). Whereas on the one hand, well-paid high-skill work was pushed by foreign investment and the development of urban centers, there is still, on the other hand, a high percentage – 68% of the total workforce – of low-wage workers in the informal sectors of the regional economies. Of the world's 2 billion informal workers, 1.3 billion live in the Asia–Pacific region (ILO 2020). As collateral of this, labor market institutions and means of collective bargaining are generally weak in the region, which contributed to workers' vulnerability as they were confronted with the COVID-19 crisis. Consequently, dramatic losses of working hours, jobs, and, correspondingly, labor income have occurred during the pandemic, with the worst losses in South Asia. Due to this crisis, there are an estimated 20–25 million additional poor working people in the Asia-Pacific region. Losses in working

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hours/jobs affected women and young people (15–24 years) above average (ILO 2020). Governments in the region have tried their best to compensate and help companies to retain workers. But, as advanced economies have much more resources for crisis response and compensation measures than low-income economies, inequalities in the region have risen (ILO 2020).

For future development, the ILO Asia–Pacific Employment and Social Outlook 2020 refers to the Sustainable Development Goal (SDG) 8 for "sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" (ILO 2020; UN online). As a corresponding pathway towards social inclusion and decent work, action is recommended towards the human-centered future of work outlined in the ILO Centenary Declaration for the Future of Work and its three areas (ILO 2019a,b;2020):

(i) increasing investment in people's capabilities
(ii) increasing investment in the institutions of work and
(iii) increasing investment in decent and sustainable work.

1.2 Technology Affecting Jobs in Asia

In their Asian Development Outlook 2018, the Asian Development Bank focused specifically on how technology affects jobs. Concerning job losses due to new technologies, the report states that there is a very low probability of jobs being replaced by automation (ADB 2018, p 66ff). There are, however, substantial changes regarding tasks and respective skills due to digitalization effects.

Table 1 shows five categories of tasks occurring in a variety of occupations, which are subject to changes in their relative importance during the digitalization process.

Table 1. Categories of tasks within occupations and industries (ADB 2018, p. 90)

Category	Interpretation	Examples of specific tasks
1: Social interaction and influencing	Frequency of nonroutine interactive tasks	Influencing and advising other people; teaching; giving speeches or presentations; negotiating with people inside and outside of firm; planning the activities of others
2: Cognitive nonroutine	Frequency of nonroutine cognitive tasks	Writing letters, emails, or articles in newspapers, magazines, or newsletters; preparing charts, graphs, or tables; using advanced math or statistics such as complex algebra, trigonometry, or regression analysis; solving complex problems

(*continued*)

Table 1. (*continued*)

Category	Interpretation	Examples of specific tasks
3: Cognitive routine	Frequency of routine cognitive tasks	Calculating prices, costs, or budgets; using or calculating fractions, decimals, or percentages; using a calculator or spreadsheet software
4: Manual	Frequency of manual tasks	Relying on hand or finger dexterity (methodology and data do not allow manual tasks to be disaggregated into routine and nonroutine)
5: ICT*	Use of ICT at work	Ranging from no ICT use to performing complex tasks such as programming

* Information and Communication Technology

Some of these different task categories become more, others less important in the process of digitalization. Figure 1 shows, for selected Asian economies, the annual growth rates of employment depending on the intensity of the respective task categories in the respective jobs. Data are also shown separately for all workers – wage and self-employed together – and for wage workers alone. As an example, employment in Indonesia – considering all workers – grew in jobs with a *high* intensity of nonroutine cognitive tasks, whereas employment contracted in jobs with a *low* intensity of nonroutine cognitive tasks (Fig. 1, upper left; ADB 2018, p. 89ff). For Indonesian wage workers alone, employment in jobs with a *low* intensity of nonroutine cognitive tasks did not contract, but grew considerably less than employment in jobs with a *high* intensity of nonroutine cognitive tasks.

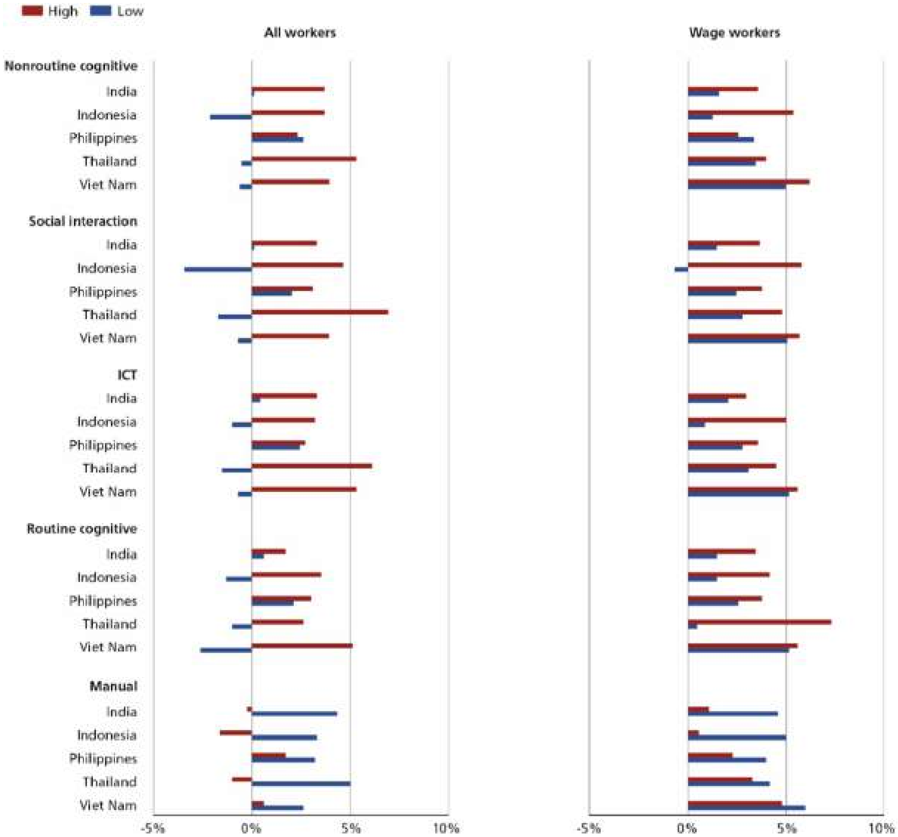

Fig. 1. Annual employment growth by task intensity (selected Asian economies, own illustration base on ADB 2018, p. 92)

The general pattern shows that ….

- … occupation *grows* most in jobs with a high intensity of nonroutine cognitive, socially interactive, and ICT tasks, and a low intensity of manual tasks, whereas …
- … occupation *grows less or even contracts* in jobs with a high intensity of manual tasks.

In a similar line of analysis, Khatiwada and Veloso (2019, ADB 2018) analyzed emerging occupations in selected Asian countries by identifying new job titles. Figure 2 shows that these emerging occupations are especially prevalent in ICT and other science and technology-based domains. Wages also tend to be higher in occupations with new as compared with occupations with old titles. This emergence of new occupations is also one of the reasons for the assertion mentioned above, that a reduction of employment – across all occupations – due to automation is not very probable.

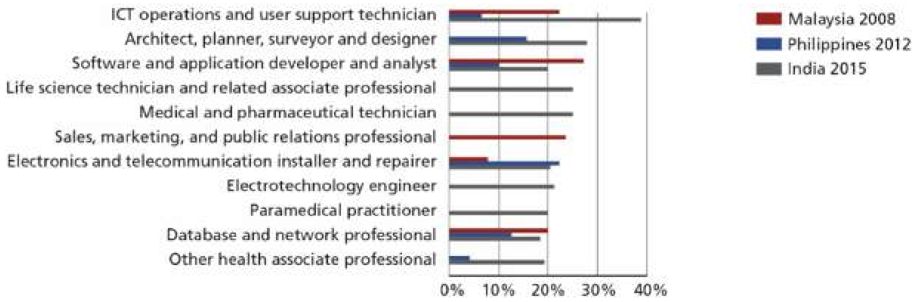

Fig. 2. Occupations with the highest proportion of new job titles (selected Asian economies, own illustration based on ADB 2018, page 86, data source: Flaminiano et al., forthcoming)

1.3 Work and Wellness

In the context of the COVID-19 pandemic, the Asian Development Bank focuses – in their Asian Development Outlook 2020 Update: Wellness in Worrying Times – on the issue of wellness as a crucial factor for maintaining physical and mental health, and for past pandemic recovery (ADB 2020b).

In the report, four cross-cutting wellness policy domains are distinguished (ADB 2020b, p. 117ff):

1. Create a healthy built environment
2. Enable and support physical activity
3. Encourage healthy eating
4. Enhance wellness in the workplace

In their background paper on workplace wellness to this report, Yeung and Johnston (2020) perceive Asia's workforce as 'unwell', based, among other sources, on comparative occupational health and safety data, which show a worse status in Asia as e g. compared to OECD countries (cf. also Fan et al. 2020). There is a strong tendency towards excessively working overtime in East Asia, with different patterns across countries: In Japan, for example, the higher, managerial ranks of the workforce are more affected by excessive overwork, whereas in the People's Republic of China, this holds more for low-rank, low-skilled workers (Tsai et al. 2016). This excessive overwork appears to be a crucial precondition for cardiovascular diseases (Chang and Lin 2019).

As a holistic framework for workplace wellness, Yeung and Johnston (2020) suggest a fourfold approach:

1. Ensure physically safe working conditions and healthy work environments.
    a. Reduce hazards and prioritize safe and healthy work conditions
    b. Create healthy and wellness-enhancing (built) work environments
2. Promote healthy behaviors at work
    a. Use design (e.g. ergonomic design of tools, equipment, and work systems) and amenities (e.g. on-site fitness facilities) to drive healthy behaviors during the workday
    b. Cultivate healthy relationships and encourage friendships among colleagues
3. Cultivate a healthy work culture
    a. Recognize and mitigate overwork and stress
    b. Integrate wellbeing into leadership
    c. Align work with personal values, intrinsic motivations, and purpose
4. Support healthy habits outside work
    a. Address diverse employee needs and cultural contexts
    b. Extend wellness benefits beyond immediate employees to families and community issues

1.4 Digital Work and Labor Platforms in Asia

Digitalization has made it possible to source/outsource tasks globally. In Asia, especially India, the Philippines, and Pakistan receive a substantial inflow of work and earnings from abroad, via freelance platforms (Fig. 3).

As defined in the ILO World Employment and Social Outlook 2021, “Digital labour platforms can be classified into two broad categories: online web-based and location-based platforms. On online web-based platforms, tasks or work assignments are performed online or remotely by workers. These tasks may include carrying out translation, legal, financial and patent services, design and software development on freelance and contest-based platforms; solving complex programming or data analytics problems within a designated time on competitive programming platforms; or completing short-term tasks, such as annotating images, moderating content, or transcribing a video on microtask platforms. The tasks on location-based platforms are carried out in person in specified physical locations by workers and include taxi, delivery and home services (such as a plumber or electrician), domestic work and care provision” (ILO 2021b, p. 1).

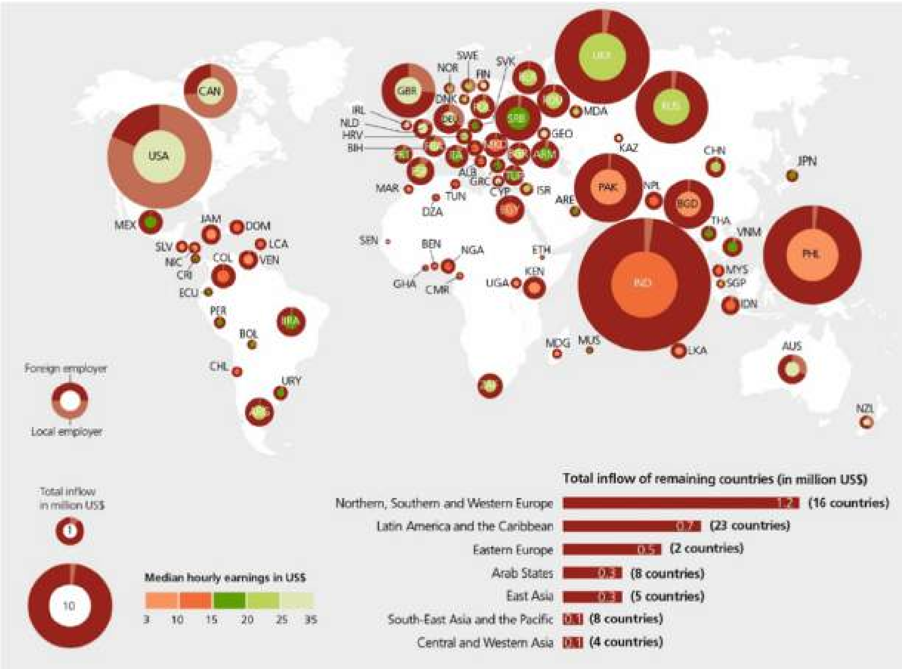

Fig. 3. Inflow of work and earnings via freelance platforms (own illustration based on ILO 2021a, p. 45, data collected by Fabian Braesemann, Oxford Internet Institute, iLabor project. For country codes, please see reference[1])

According to the ILO World Employment and Social Outlook 2021, about 96% of the investment in digital labor platforms is concentrated in Asia (US$56 billion), North America (US$46 billion), and Europe (US$12 billion), compared to 4% in Latin America, Africa and the Arab States (US$4 billion) (ILO 2021a, p. 20).

[1] Country codes: Albania (ALB), Algeria (DZA), Argentina (ARG), Armenia (ARM), Australia (AUS), Bangladesh (BGD), Belarus (BLR), Benin (BEN), Bolivia, Plurinational State of (BOL), Bosnia and Herzegovina (BIH), Brazil (BRA), Bulgaria (BGR), Cameroon (CMR), Canada (CAN), Chile (CHL), China (CHN), Colombia (COL), Costa Rica (CRI), Croatia (HRV), Cyprus (CYP), Denmark (DNK), Dominican Republic (DOM), Ecuador (ECU), Egypt (EGY), El Salvador (SLV), Ethiopia (ETH), Finland (FIN), France(FRAU), Georgia (GEO), Germany (DEU), Ghana (GHA), Greece (GRC), India (IND), Indonesia(IDN), Ireland (IRL), Israel (ISR), Italy(ITA), Jamaica (JAM), Japan (JPN), Kazakhstan (KAZ), Kenya(KEN), Madagascar (MDG), Malaysia (MYS), Mauritius(MUS), Mexico (MEX), Morocco (MAR), Nepal (NPL), Netherlands (NLD), New Zealand (NZL), Nicaragua (NIC), Nigeria (NGA), North Macedonia (MKD), Norway(NOR), Pakistan (PAK), Peru (PER), Philippines (PHL), Poland (POL), Portugal(PRT), Republic of Moldova (MDA), Romania(ROU), Russian Federation (RUS), Saint Lucia (LCA), Senegal (SEN), Serbia (SRB), Singapore (SGP), Slovakia (SVK), South Africa (ZAF), Spain (ESP), Sri Lanka (LKA), Sweden (SWE), Thailand (THA), Tunisia (TUN), Turkey (TUR), Uganda (UGA), Ukraine(UKR), United Arab Emirates (ARE), United Kingdom (GBR), United States (USA), Uruguay (URY), Venezuela (VEN), Viet Nam (VNM).

The demand for work on online web-based platforms largely originates from developed countries, while the labor supply originates predominantly from developing countries (ILO 2021b, p. 3). Furthermore, "Digital labour platforms globally generated revenue of at least US$52 billion in 2019. About 70% of the revenues generated were concentrated in just two countries, the United States (49%) and China (23%), while the share was much lower in Europe (11%) and other regions (17%)" (ILO 2021b, p. 3).

The rise of digital labor platforms has provided new opportunities for work, earnings, and livelihood, predominantly for workers in developing countries. At the same time, it has brought about challenges for workers, e.g. …

- … "regularity of work and income,…
- … working conditions, …
- … social protection, …
- … skills utilization, …
- … freedom of association …
- … and the right to collective bargaining" (ILO 2021b, p. 2).

As a way forward to improve the status and rights of digital platform workers, it has to be taken into account that digital platform work is by its very nature international and cuts across different legal and administrative systems. The ILO Maritime Labour Convention, set up in 2006, can be regarded as a precedent as it concerns, in a similar way, an industry with multiple parties operating across different jurisdictions (ILO 2021b, p. 9).

The People's Republic of China is one of the world's largest platform economies, which, as described above, also holds for digital labor platforms (Chen 2021). Unlike in Western countries, digital platforms and platform work have been promoted by PRC's government and state-sponsored media (Chen 2021, p. 6). Furthermore, "whereas Western platform models were construed as primarily a business solution, the developer of China's first platform, K68.cn, viewed platform work in China as a mutually beneficial exchange that came to be known as 'Witkey,' a term derived from a combination of the words 'wisdom' and 'key,'. He envisioned platforms as providing an infrastructure to effectively match those in need of wisdom, ideas, input, or assistance with the sources that could provide the 'keys' in the form of solutions" (Chen 2021, p. 6). Chinese digital labor platforms also offer a type of service – craft and assembly work– usually not found on Western digital labor platforms; this work is typical industrial work, but mediated by a digital platform (Chen 2021, p. 7).

A survey performed on behalf of ILO with more than 1,000 participating Chinese digital platform workers found that Chinese digital platform workers, as compared with their Western counterparts, are more dominantly male (about 70% of all digital platform workers) and a bit younger (25–27 years) (Chen 2021, p. 13).

One issue to be solved in the future is fees for the platform services charged by the platforms to workers, thus reducing their income. In China, some platforms additionally require workers to provide a guarantee deposit, which might be confiscated if the work is not done sufficiently. This practice of charging fees is in conflict with international labor standards (Chen 2021, p. 39).

Wood and co-authors (2019) investigate the social situation of digital workers in the gig economy in Southeast Asia and Sub-Saharan Africa. They find two sides of social (dis)embeddedness of digital platform workers. On the one hand, they are *normatively* disembedded from labor regulations, workers' rights, collective bargaining, and social security systems, as their work is largely commodified. On the other hand, they are embedded in trust-based *networks* with other digital platform workers and clients.

1.5 Gender Issues

Labor market participation is generally lower for women as compared to men. Additionally, motherhood and fatherhood have very different effects: While fathers' employment rates tend to be higher than those of men without children, mothers' employment rates are lower than those of women without children (Fig. 4). A major factor behind these differences is the uneven distribution of unpaid work, especially care work. While more than 50% of women who are not participating in the labor market indicate unpaid care work as the main reason, this holds only for less than 10% of men staying outside the labor market; while unpaid care work is the most important reason for women to stay outside of the labor market, it is the less important for men, for whom reasons like being in education, sick or disabled are more important (UNESCAP 2019, p. 18).

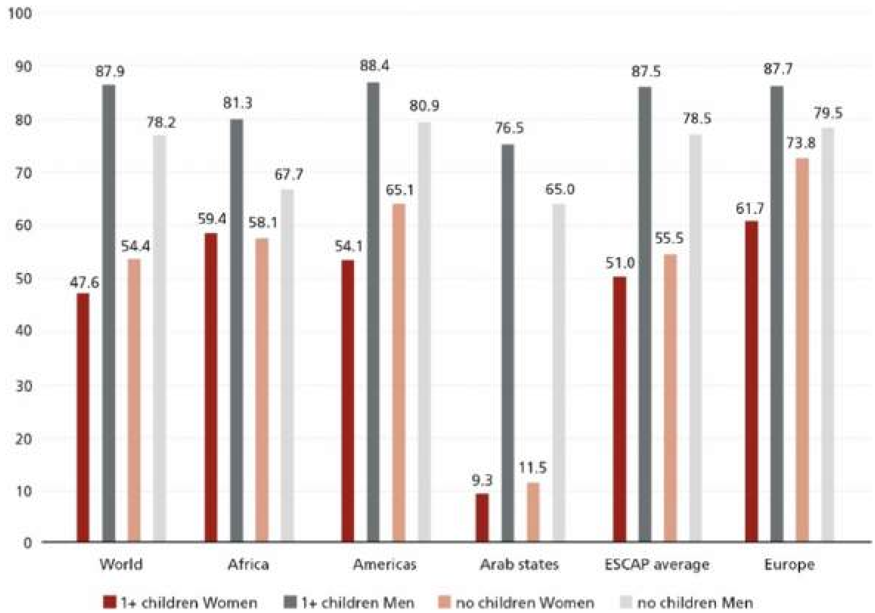

Fig. 4. Male and female employment-to-population ratios, by motherhood/fatherhood and world regions (own illustration based on UNESCAP 2019, p. 20, data collected by ILO, 2018). ESCAP: Regions in Asia and the Pacific as defined by the United Nations Economic and Social Commission for Asia and the Pacific.

While the differences between male and female employment-to-population ratios are bigger in Asia and the Pacific as compared to Europe (and also, to a lesser extent, as compared to the Americas), they are very close to the world averages (Fig. 4).

Huge differences, however, become evident when Asian/Pacific subregions are differentiated (Fig. 5). While the gender gap in employment is rather small or moderate in the Pacific Islands (below 10 percentage points) and East Asia (between 10 and 20 percentage points), it is very big in South Asia (over 50 percentage points).

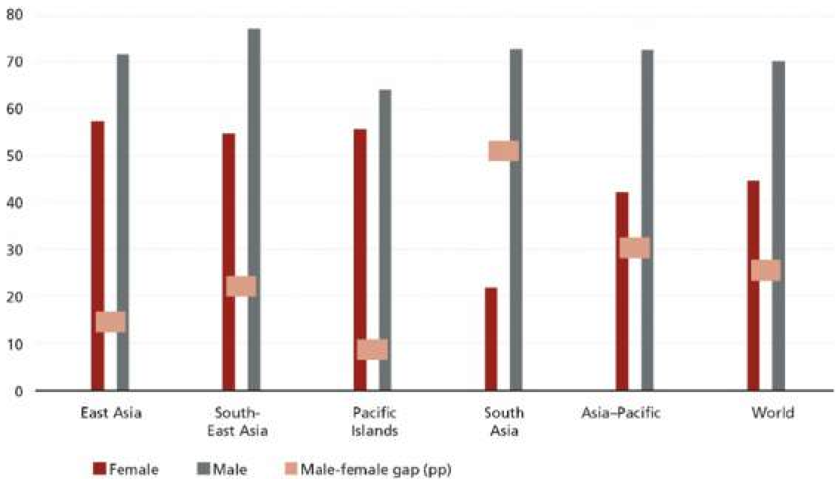

Fig. 5. Male and female employment-to-population ratios, by Asian/Pacific subregions, 2019, percentages (own illustration based on ILO 2020, p. 3)

This pronounced gender gap in South Asia can be at least partially explained by the so-called Indian paradox: While educational achievement of women is rising, women's employment is declining (Chatterjee et al. 2018; Desai, Joshi 2019). In India, the relationship between the education level achieved by women and their labor market participation is U-shaped: It *declines* from low to moderate education levels, and then rises from moderate to high levels of education. Based on their research, Chatterjee and co-authors suggest several reasons for this – seeming – paradox:

1. A medium level of education allows women to marry well-educated men with higher incomes, which allows them to withdraw from the labor force; there is strong empirical evidence for this income-effect.
2. Also, there might not be enough salaried positions being perceived as suitable by women with intermediate education levels. In this context, the curvilinear relation between women's education levels and labor force participation appears to be the integral of three linear relationships, two negative and one positive: A negative relationship for work in family businesses and farms, also a negative relationship for wage work, and a positive relationship with salaried work.
3. Furthermore, culturally determined gender norms attribute higher status to non-working women.

Although the female employment-to-population ratio is higher in South Korea than in India, it is still the lowest among OECD member countries. Especially for highly educated women, the employment rate of Korean female college graduates is the lowest (about 60%) among OECD nations with the widest gender gap of almost 30 percentage points between male and female graduates (Kang, Wang 2018).

Korean – and Japanese – women often interrupt their careers when becoming mothers, then returning to work in their mid-forties, when their children attend school. Consequently, their labor force participation pattern over time resembles the letter M, in contrast to the inverse-U-shaped curve found for women in developed Western countries. After their career interruption for childcare, they tend to be offered positions on a lower level as compared to their earlier positions. For highly educated Korean women, the career curve may even be L-shaped: They cannot find suitable employment at all after their career interruption, which then turns out to become a career termination (Kang, Wang 2018; Jung 2018). Wang and Kang (2018) – in a qualitative research approach – look into the specific challenges for married, highly educated Korean mothers to achieve work-life balance. Two challenges are salient: Firstly, the traditional, Confucian values regarding marriage and family strongly emphasize women's roles in the domestic context, as spouses and mothers. Secondly, work culture in Korea – with excessive overtime, after-work socializing, company dinners, etc. – is oriented towards male breadwinners with a minimum of domestic – household, family – obligations, or none at all. Married, highly educated Korean mothers need resources to navigate these challenges. Often, these resources – in terms of time and energy – are not provided by their husbands, but rather by their mothers and mothers-in-law, who invest and engage heavily to take major responsibilities in caring for their daughters' or daughters'-in-law children – up to raising them completely in their own homes during the week. Finally, Wang and Kang (2018) articulated some optimism with respect to the younger Korean generation, where these cultural norms tend to change, and where young fathers are more prepared to take responsibility to care for their children.

Another source of optimism might be specific effects of digitalization on the situation of female workers (Chun and Tang 2018). The authors find – for the economy of Vietnam – that companies' adoption of broadband internet and similar ICT increased their relative demand for female and college-educated workers. This effect is specifically strong in sectors heavily relying on manual tasks; here, ICT tends to replace these manual tasks, predominantly performed by male workers, by more non-routine and communicative tasks, where women have a comparative advantage. In sectors with the highest demands for technical ICT skills, however, this trend is weaker, highlighting the need for more participation of women in STEM[2] education.

1.6 Key Challenges and Policies in Taiwan

After this general overview of digital work in Asia, Taiwan will be considered in more detail as a case study. Taiwan is among the most advanced economies in Asia and worldwide. Consequently, Taiwan's digitalization strategies focus on maintaining and

[2] Science, Technology, Engineering, and Mathematics.

fostering this advanced position. In a cross-departmental approach, Taiwan has addressed …

- … talent development for advanced digital technologies, especially AI,
- …increased research activities, especially in international contexts,
- …bringing together talents, research institutions, and industry to boost innovation, with a special emphasis on tailored support for small and medium enterprise (SMEs) and …
- … providing a favorable legal and regulatory framework.

As a world-leading semiconductor manufacturer, a core issue of Taiwan is to promote AI-on-Chip technologies, to further develop the country's competitive edge. This is a core aspect of the strategic approaches mentioned above.

2 In-Depth Analysis: Taiwan

2.1 Trends in Beneficial Infrastructure and Smart City for Digital Innovation

According to the 2021 World Competitiveness Yearbook released by the Switzerland-based International Institute for Management Development (IMD), Taiwan has emerged as the eighth most competitive economy (Taiwan News 2021). Digital economy and COVID-19 have increased the demand for digital technologies and also pushed the government to increase the pace toward digital transformation. For Taiwan, key opportunities will arise from the incoming need for facilities, services, and talent. Reassessing the use of applications such as remote technology, AI (artificial intelligence), big data, IoT (Internet of Things), and hybrid cloud infrastructure is a must for all sectors to sharpen their adaptive abilities in these ever-changing times. Taiwan's broadband infrastructure is near mature after a series of Information and Communications Technology Initiative (ICT) policy promotions. To compete with other advanced countries in the development of innovative applications and services, Taiwan is continuously optimizing broadband infrastructure, intending to complete the ICT ecosystem in Taiwan, thereby promoting the development of the digital economy.

In 2017, the Executive Yuan[3] started promoting the Digital Nation and Innovative Economic Development Program (also known as "DIGI$^+$") as an administrative blueprint for leading digital development and innovation. The goals of the DIGI$^+$ program (Development, Innovation, Governance and Inclusion) and the Smart Cities/Townships Regional Innovation Action Plan are to promote urban and rural joint ecosystems and create high quality of life for sustainability. The future appearance of smart cities/townships includes environmental sustainability, convenient transportation, safety and disaster prevention, and regional innovation. The expected benefits include the expansion of Taiwan's digital economy to US$213.73 billion, the penetration rate for broadband internet connections of 2 gigabits per second will be rolled out to cover 90% of users, and citizens will be guaranteed the basic right to 25 megabits per second broadband service (BOST 2018). With a shift in focus toward IoT technology, Taiwan's domestic industries will

[3] Government of Taiwan, executive branch.

continue to lead the world in the digital age, further bolstering Taiwan's international competitiveness.

Today, 55% of the world's population lives in urban areas, by 2030, the world is projected to have 43 megacities with more than 10 million inhabitants, most of them in developing regions (UN 2018). With the increasing urban population, traffic congestion, environmental problems, and climate change, applying ICT technologies in urban governance can enhance the quality of life of citizens and assist industrial development. The population of Taiwan is concentrated in six major cities. Although the population is below Megacity level (at least one million people), the population density of several metropolitan areas, especially Taipei City (9,934 people per square kilometer), is similar to or even exceeds the level of international Megacities. Therefore, in terms of population density, such urban areas in Taiwan also share the common governance issues faced by Megacities.

The government has invested in fostering industrial development of 5G/B5G wireless communication networks and 6G technology for the continued expansion of wireless communication coverage. Over the last four decades, Taiwan's tech industry has been a global leader in this revolution, most notably in the areas of semiconductors, cutting-edge ICT, and comprehensive supply chains. As the world continues toward a digital future of 6G, autonomous vehicles, space technology, and other digital innovations, facilities, services, and talent are drivers of the digital transformation. Taiwan is positioned to maintain its leadership role in the digital era by integrating facilities and services; supporting the research and development of AI, big data, and advanced telecommunication networks; and providing funds for forward-thinking research projects in the semiconductor industry. Taiwan's digital transformation will continue to redefine traditional conceptions of industry and lead the country toward becoming a world-class digital nation and a land of intelligent technology.

2.2 Current Level of Digitalization in Taiwan

To accelerate industrial Innovation and create the "Digital Nation, Smart Island", Taiwan's government has promoted the "Digital Nation & Innovative Economic Development Program ($DIGI^+$) 2017–2025", which is intended to enhance digital infrastructure, re-construct a service-based digital government, and realize a fair and active internet society with equal digital rights. The government has approved a 4-year, US$ 658 million spending plan for 5 G technologies to increase the region's digital competitiveness. Based on the Taiwan E-Competitiveness Annual Report (BOST 2018), the government has initiated "$DIGI^+$ program" and "AI Taiwan" program to achieve a vision of becoming a high-value digital nation, the "$DIGI^+$ program" has set out three major indicators: "Active Internet Society", "Innovative Digital Economy", and "Advanced Broadband Environment".

(1). **Active Internet Society:**

- By 2020, the digital living service adoption of the general public will reach 60% and further reach 80% by 2025.

- By 2020, Taiwan hopes to acquire top 12 of the global national e-competitiveness ranking and reach top 6 by 2025.

(2). **Innovative Digital Economy:**

- Digital economy is estimated to contribute 25.2%, or NTD 4.8 trillion, of Taiwan's GDP in 2020, up from 20.3%, or NTD 3.4 trillion in 2015 and expected to reach 29.9%, or NTD 6.5 trillion, in 2025.
- Production value of digital software economy will increase from NTD 1.1 trillion in 2015 to NTD 1.7 trillion in 2020 and further to NTD 2.9 trillion in 2025.

(3). **Advanced Broadband Environment:**

- By 2020, broadband internet is to reach speeds from the current 100 Mbps to 1 Gbps (with 90% internet coverage), which is 10 times faster; by 2025, the speeds are to reach 2 Gbps (with 90% internet coverage).
- By 2020, Taiwan is set to make "broadband human rights" a reality while ensuring disadvantaged people have access to 10 Mbps broadband services and further to 25 Mbps by 2025.

The "AI Taiwan" program aims to achieve three main objectives through five action plans and strategies (Table 2).

(1). Cultivate 1,000 high-end AI talents to develop AI technology by 2021, alongside 10,000 pioneers to broaden AI application in different industries.
(2). Use the AI Pilot Project to promote AI on Device, allowing Taiwan to become one of the top 3 AI chip manufacturers in the world.
(3). Enhance the promotion of talent and industry cultivation to help Taiwan achieve number one in specific AI application industry sectors.

Table 2. AI Taiwan's five action plans and strategies (Source: Digital Innovation & Governance Initiative (DIGI+) Committee, Executive Yuan, compiled by III-MIC, October 2018).

Action plan	Strategies	Unit in charge
AI Talent Program	Cultivating smart technology elites	Ministry of Science and Technology (MOST), Ministry of Education (MOE), Ministry of Economic Affairs (MOEA)
	Training smart education Pioneers	MOST, MOE, Ministry of Labor (MOL)

(*continued*)

Table 2. (*continued*)

Action plan	Strategies	Unit in charge
	Attracting Global AI Talent	MOEA, MOST
AI Pilot Project	Focus on research and discovering niche advantages	Office of Science and Technology, MOEA
	Develop world-class advanced AI research network	MOST, MOEA, National Center for Cyber Security Technology (NCCST), MOE
AI International Innovation Hub	Foster 100 AI-related startups	MOEA, MOST
	Develop international AI clusters	MOEA, MOST
Open Test fields and regulations	Open fields and data for testing	MOEA, MOST, Environmental Protection Administration (EPA), Ministry of Transportation and Communications (MOTC), Ministry of Interior (MOI)
	Research and analyses in AI related laws and regulations	National Development Council (NDC), Board of Science and Technology, Executive Yuan (BOST), relevant ministries and departments
AI for industrial innovation	Match 5 + 2 industrial innovation with AI talents	MOEA, MOST, NDC, Council of Agriculture (COA), MOE, MOL
	Enable AI-driven innovation in SMEs	MOEA, MOST

In 2019, 60% of Taiwan's enterprises have implemented digital transformation plans, yet only 13% of Taiwan's SMEs have initiated digital transformation-related projects due to resource and budgetary constraints (CPC 2020). According to the report of Taiwan's digital imperative (McKinsey 2017), knowledge-intensive industries are highly digitized, financial services such as banking and insurance, and high-tech, are the most highly digitized sectors of Taiwan's economy. Public industries are notably advanced digitally. Taiwan's government has invested at least US$200 million every five years since the 2000s in digital assets and processes. Service industries vary widely in their level of digitalization. Transportation is the most digitized among Taiwan's service sectors because of a booming e-commerce market and an increase in online services and transactions. Other service sectors such as wholesale and retail trade are relatively less digitally advanced. Manufacturing industries in Taiwan have been slow to digitize. Chemical manufacturing represents approximately 10% of Taiwan's GDP but is less digitized than other manufacturing sectors (Fig. 6.).

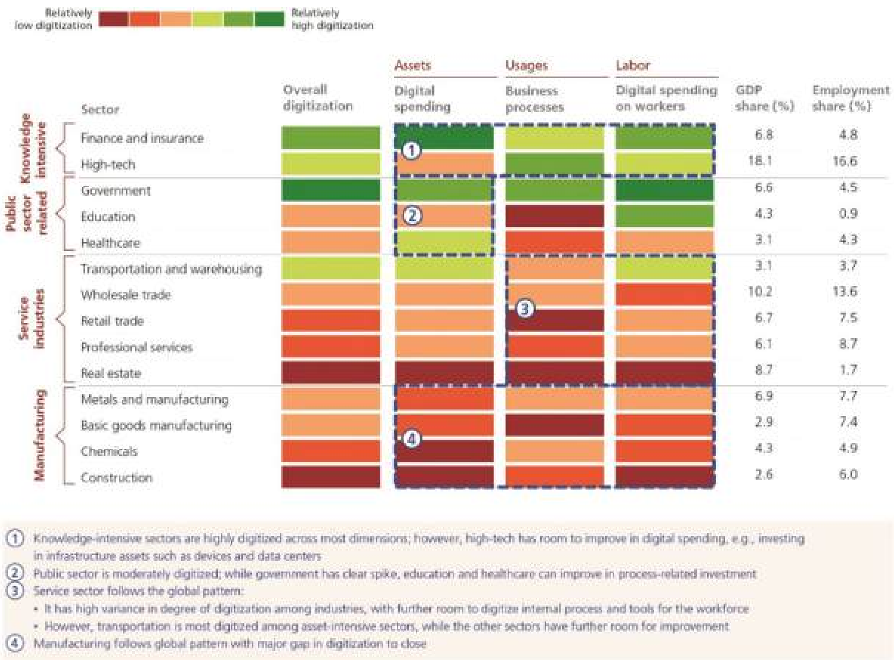

Fig. 6. The Taiwan Digitazation index, 2016 or latest available data, only displayed sectors with GDP contribution at 2% (own illustration based on McKinsey 2017, p. 13; data source: Gartner, Taiwan Directorate General of Budget).

In recent years, Taiwan's government has joined forces with manufacturers to promote distinctive, differentiated, high-value-added products and applications that will drive the next wave of the nation's digital industrial transformation and expansion. Several accomplishments have been reached through the process of digital transformation as the followings (MOEA undated):

(1). Smart manufacturing in printed circuit boards: the time to eliminate defects is reduced from 30 days to 7 days (Time-saving: 75%) and the false alarm rate of defect detection is reduced by 50%.
(2). Smart manufacturing in the textile industry: increase 20% of defect-free units, the success rate of the initial color matching is increased by 5% and the energy saving is 15%.
(3). Smart manufacturing of aerospace machine tool industry: shorten product delivery time by 30%, increase productivity by 10% and reduce production costs by 10%.
(4). Smart manufacturing of servo motors: drive 2.5 times of daily output (Increase the units from 150 to 525 units per 8 h day).
(5). Smart manufacturing of water hardware and hand tool industry: increase 60% of output per capital of labor force (from US$ 60,000 to US$ 96,000).
(6). Smart manufacturing of automotive and motor vehicle industry: the total equipment efficiency has increased from 80% to 85%.

2.3 Digitalization of the Labor Market in Taiwan

Under the transformation of the digital industry, three major phenomena can be detected in the changes in Taiwan's employment market: the need to upgrade talents, especially those with cross-domain digital skills; the industry lacks the awareness regarding digital talent training; the gap between industry and academia is widening, which signifies that reducing the learning gap has become the key to the efficiency of the employment market in Taiwan. According to a survey report by the Taiwan Economic Research Institute (2019), about 60% of enterprises in Taiwan have tried to introduce new technology. Most of such technical fields take smart manufacturing as their mainstream, followed by IoT security, big data analysis, and artificial intelligence; based on corporate investment with regard to the level of digital transformation, companies generally believe that the demand for employment driven by various new technologies is greater than the demand for saving manpower. Taking electronic information as an example, future areas of manpower that companies need to increase will be focused on cloud computing and information security in the IoT. Companies believe that, on the one hand, internal employees are still inadequate in their grasp of new technological capabilities; on the other hand, it is difficult to hire suitable talents from outside. The development of digital technology has changed manufacturing behavior in global industries and has also accelerated the demand for the upgrading of talents and skills.

In the future, talent cultivation needs to attend to the skills of professionalism. What is more, digital skills that solve problems via information technology should be duly cultivated. Taiwan is dominated by small and medium-sized enterprises, and most smart systems and equipment are huge investments, which turn out to be a burden for corporate transformation. Limited by the company size and the impact of industrial Original Equipment Manufacturer (OEM), the digitalization of most companies' industrial investment ends up being relatively conservative; coupled with the introduction of digital smart equipment, relevant skill training is required, albeit these companies can only afford limited means in independently training their digital talents, hence external assistance is still indispensable. In addition, the rapid changes in technology also make it difficult for companies to predict what type of digital capabilities they need in the future, while the existing knowledge or skills may end up insufficient in response to the development of an innovation economy in a timely manner. How to keep the digital skill and expertise edge depends on continuous skill training conducted in a scrolling style. Changes in the quality of Taiwan's labor force have been unable to effectively meet the needs of industry employment. Consistent with the trend of the popularization of higher education, the age at which young people enter the workforce has been delayed. How to reduce the gap between learning and employment has become the key to activating the efficiency of Taiwan's employment market. The main purpose of enterprises participating in the cultivation of talents for industry-university cooperation is to recruit the talents needed for current jobs and to cultivate the reserve talents needed for the future. However, the gap between learning and employment has reduced enterprises' willingness in engaging in industry-university cooperation.

To face labor and talent shortages, the government needs to strengthen the coordination mechanism of its digital skills development policy, connect the cultivation mechanisms in both major systems, i.e., integrate resources to initiate cooperation between the supply and demand of talents, design digital talent training standards and incentive mechanisms, promote corporate investment in talent training, establish a new form of industry-university cooperation model, establish a learning certification system, and gradually guide the transformation of talents. Talent competitiveness can be continuously maintained through a wider range of opportunities for lifelong learning.

2.4 Talent Development and Cultivation in Taiwan

Digital competences are the cornerstone of a digital economy, talent development accompanied by industrial innovations is the key to a country's competitiveness. In Taiwan, digital talents have been recognized in the DIGI$^+$, the AI Taiwan action plan, and the nationwide six core strategic industries policy. Taiwan's government educates digital talents by augmenting the IT infrastructure and constructing an e-learning environment. Most importantly, building a talent supply chain from compulsory education to universities, internships, and on-the-job training has facilitated digital competences on different levels and paved the way for the transformation into a digital economy.

The action plan for the development of cross-disciplinary digital talents consists of five venues: elementary schools, junior high schools, colleges and universities, on-the-job training, and introduction of software competences from overseas. The purpose is to accelerate the development of professional know-how in both hardware and software, in support of innovation and development of industries.

1. Construct a smart learning environment for high and elementary schools: Taiwan's government implements the deployment of smart networks on campus, strengthening a digital teaching and learning environment, and the improvement of broadband connectivity and speeds for the Taiwan Academic Network.
2. Establish the foundation of K-12 education and explore the potential elite: deepening of IT education as part of 12-year compulsory education by developing computing concepts and digital literacy for students, assisting teachers in primary and junior high schools regarding the enhancement of IT expertise and discovering students' IT potential with a development mechanism included into the national curriculum.
3. Expand the cultivation of university student's inter-disciplinary digital skills: the action plan includes the development of 5G networking and application competences, administering of the integration of academic, industrial and research efforts, and internationalization of digital economy professionals by fostering the links between corporations and the new generation of international talents.
4. Support the cultivation of inter-disciplinary digital skills of the workforce: the organization of training and education programs for multi-disciplinary digital talents in order to support the innovation and the development of industries and the encouragement of on-the-job training and education schemes by companies for cross-disciplinary digital competences are two major programs to support the transformation of the digital economy.
5. Link international open innovation resources to facilitate the talents' ability to design and develop: the government sponsors R&D projects on open source software and encourages active participation in open source initiatives to enhance Taiwan's contribution to the global community.

Aligning with the national policy directory "Digital Nation, Smart Island," the expected outcomes of talent development are as following:

I. Cultivation of 1,000 Elites in Intelligent Technologies: this includes 1,000 high-caliber talents in intelligent technologies by 2021, 800 AI talent prospects from the universities, 200 high-caliber talents in intelligent system technologies from the research organization, and encourage international enterprises to establish AI R&D centers.
II. Training of 10,000 Pioneers in Intelligent Applications: this includes 5,000 talents in practical intelligent technologies, 2,000 university talents per year in cross-domain intelligent applications, 2,000 corporate employees per year in intelligent applications, and 1,000 people per year trained in secondary skills.
III. Recruiting Global AI Talents: the government implements New Act for the Recruitment and Employment of Foreign Professionals, expand programs for attracting worldwide AI talents and promote the innovative clusters of AI talents and provide a convenient living and educational environment.

2.5 National Promotion Strategy for Digital Economy

Artificial intelligence (AI) has fundamentally transformed human life and industry and created boundless business opportunities. Taiwan government rolled out the AI Taiwan Action Plan (2018–2021) in 2018 to sharpen Taiwan's advantages. Several national promotion strategies are implemented to propel Taiwan into the ranks of the world's leading smart nations.

1. Digital culture and creativity: Promote the sound development of cultural industries through technological tools and develop diversified digital content and innovative applications.
2. Data economy: create a data application atmosphere and develop data economy value-added services and guide the transformation of the existing industry to provide data service.
3. Digital e-commerce: promote cross-border e-commerce and develop international business opportunities, provide convenient financial and technical service, and popularize and promote SME mobile payment.
4. Software and hardware integration: accelerate the exchange between domestic startup teams and international communities and establish a comprehensive soft-landing mechanism in Taiwan to increase the incentives for international teams to come to Taiwan. Promote digital service innovation and incubate flagship teams with the capacity to output software and hardware integration service internationally.
5. Digital base: construct national-level AI R&D and cloud service infrastructure, develop the software/hardware technology and service of forward-looking smart application, and bridge AI ecosystem to industrial application and talent cultivation.
6. Developing AI talent: Smart-tech researchers for senior-level positions are being trained by universities and research institutes, while more than 10,000 AI technicians and applications specialists are produced each year.

7. Promoting Taiwan's lead role in AI: Taiwan's government is working aggressively to expand the nation's world-leading position in the semiconductor chip industry.
8. Building Taiwan into an AI innovation hub: As international AI innovation clusters are formed in Taiwan, Microsoft, Google and other big names have set up AI R&D bases on the island to build connections with the local AI industry.
9. Liberalizing laws and opening test grounds: Taiwan announced the Unmanned Vehicles Technology Innovative Experimentation Act, the first of its kind in the world covering autonomous vehicles on land, at sea, and in the air.
10. Transforming industry with AI: AI talent will be matched to industrial needs to develop AI solutions and accelerate industrial innovation and digital transformation.

2.6 Outlook

The digital economy has deepened into the global economy as a key factor driving national and global economic growth, and it also has led to great impact and changes in the whole society, economy, social interaction, and work. The scope of application includes the establishment of IT-based operation, R&D of virtualized products and services, development of digitalized financial transaction and e-commerce. This not only shortens the distance among the global participants but also opens a new type of economic system that leads the global industry to cross-generation, cross-border and cross-domain.

However, SMEs are lacking relevant competences, applications, and innovations in responding to the rapid changes in digital industries. For awareness creation, the Ministry of Science and Technology (MOST) has promoted the AI Innovation Research Program and established four AI research centers, including the Artificial Intelligence for Intelligent Manufacturing Systems Research Center (AIMS). The goal of AIMS is to establish a world-class AI research center that will build on Taiwan's traditional strength in manufacturing and make critical contributions to advance it to the next level in the global market. AIMS has coordinated many outstanding research teams and projects in Taiwan in the field of intelligent manufacturing, including promising areas and applications such as AI, deep learning, machine vision, machine network, big data analysis, intelligent agriculture, intelligent machinery, etc. (AIMS 2018).

Digitalization has become a key reengineering process to regain Taiwan's companies' competitiveness and tap into digital economy opportunities. The adaptation of new process technologies and the development in manufacturing intelligence capabilities have profound effects on the management and operations, including cycle time reduction, defect diagnosis, demand forecast, support decision-making, equipment management, and human's talent extension. The support from government policy and the collaboration with academy sectors are key driving forces to engage in the digital innovation process. The need of cultivating digital talent and the right skills is also an essential element during the digital innovation process. Therefore, it is necessary to establish relevant forward-looking technologies and applications, we believe the following methods will strengthen the cooperation among industries, academic sectors, and society and drive the sustainability of a digital economy.

1. **Upgrade and transform current industries:** create opportunities for experts in artificial intelligence, statistics, manufacturing, management, science and technology law, social sciences, etc. to work together to promote interdisciplinary research and innovation.
2. **Cultivate AI talents**: collect and maintain manufacturing big data, organize AI competitions for intelligent manufacturing solutions, and utilize these events to train or cultivate AI talents that will help to enhance competitive advantages and profitability of the domestic industries.
3. **Build partnerships between academia and industry for innovation and entrepreneurship:** establish strategic alliances with industry associations and institutions, integrate and utilize academic resources, bring in domestic and foreign venture funds, and accelerate the growth of startup companies.
4. **Elevate national global visibility and influence in AI:** building on national strength to promote cooperation with leading research centers and multinational companies worldwide, and invite domestic and foreign experts to interact, share and collaborate.
5. **Export effective AI solutions for intelligent manufacturing**: promote the development and application of advanced technologies in artificial intelligence in the field of intelligent manufacturing, help the domestic industries to adopt AI or even create a brand-new AI industry, and export these technologies to other countries.

3 Conclusion and Outlook

Not surprisingly, the world of work shows many different faces in a region as large and diverse as East Asia, or the Asia-Pacific.

However, an issue affecting several countries in the region refers to ‘unwell’ working conditions: Occupational safety and health indicators are worse for Asia as compared to other continents (Yeung and Johnston 2020; Fan et al. 2020). One reason for this is excessive overwork, which is frequently encountered across Asia, while local patterns vary: In Japan, rather managerial staff is affected by excessive overwork, while in the People’s Republic of China this holds more for low-rank, low-skilled workers (Tsai et al. 2016).

A crucial phenomenon for Asian labor markets and working conditions is the rise of digital work and labor platforms: Roughly 96% of the investment in digital labor platforms is concentrated in Asia (US$56 billion), North America (US$46 billion), and Europe (US$12 billion), compared to 4% in Latin America, Africa and the Arab States (US$4 billion) (ILO 2021a). Thus, Asia attracts the lion’s share of this investment in a global comparison. This rise of digital labor platforms has provided new opportunities for work, earnings, and livelihood predominantly for workers in developing countries in the Asia Pacific region, but has also brought about challenges for workers regarding e.g. their regularity of income, working conditions, social protection, and freedom of association (ILO 2021b).

Technology and associated task structures also affect job markets and working conditions across Asia; some patterns appear to show up for several countries in the region: Occupation seems to grow most in jobs with a high intensity of nonroutine cognitive, socially interactive, and ICT tasks, and a low intensity of manual tasks, whereas occupation seems to grow less or even contract in jobs with a high intensity of manual tasks (ADB 2018).

Regarding gender inequality, the situation varies widely between Asian sub-regions. Male-female differences in labor market participation are very low in the Pacific Islands, rather low in East Asia, but extremely high in South Asia, especially India (UNESCAP 2019, ILO 2020).

Challenges for the future refer to using the potential of digital technologies for socio-economic development, and for improving the world of work at the same time.

The in-depth analysis of Taiwan has shown how this might look like in a very advanced economy, approaches need to be and are different elsewhere in the Asia-Pacific.

But, among all this diversity, the ILO Centenary Declaration for the Future of Work and its three areas of action (ILO 2019a, b; 2020) might show a common pathway:

(1) increasing investment in people's capabilities
(2) increasing investment in the institutions of work and
(3) increasing investment in decent and sustainable work

And, it might be added, research and monitoring activities are needed in every country to be able to track status and development in each of these domains, in a country-specific way.

Of course, this needs to be implemented in very different ways between the East Asian and Pacific countries, but failing to address any of the three areas will most probably have detrimental effects on the socio-economic development of any country in the region.

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Artificial Intelligence and Assistance Systems for Technical Vocational Education and Training – Opportunities and Risks

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Abstract. Artificial intelligence and Assistance Systems are having an impact on the economy, society, skilled work and work environment. However, there are often very different assessments of the effects: On the one hand the loss of jobs and even professions have been predicted, on the other hand new support and options for work are emerging.

The actual promotion of these systems will depend on the opportunities of intervention and control by skilled workers. How can problem situations and imponderabilities in virtual environments be handled and solved? Both the opportunities and the risks of Artificial Intelligence and assistance systems for vocational education and training are reflected in this article.

Keywords: Assistance system · Skilled worker · Man-Machine-Interface

1 Introduction

Skilled work and vocational learning are increasingly influenced by digital assistance systems. The actual promotion of learning by applied assistance systems or systems of Artificial Intelligence will depend on the opportunities of intervention and control by skilled workers. How can problem situations and imponderabilities in virtual environments be handled and solved? How can Artificial Intelligence support vocational learning by creating a work environment and supportive learning?

Digitalization in vocational education leads to two objectives for the shaping and thus for the didactics of vocational learning processes: Digitalization for making use of digital media/technologies (vocational media pedagogy) and digitalization as a subject of vocational educational processes (vocational didactics). These two objectives are often intermingling. The article concentrates on the digital technologies for concrete work-oriented learning and on the systemic level of vocational education and training.

2 Changes of the Man-Machine-Interface (M-M-I) in the Age of Digitalization

The promotion of learning in a digital world of work will strongly depend on how future work-processes are shaped along with the possibilities of intervention of skilled

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workers. Three theses on the design of the M-M-I are currently being discussed for the shop-floor-level (Windelband/Spöttl 2012; Schlund/Gerlach 2013; Ahrens/Spöttl 2018):

1. Tools scenario/assistance scenario – Development of expert systems with tool character for skilled work;
2. Automation scenario – Limitation of the design leeways of skilled workers and devaluation of qualifications;
3. Hybrid scenario – New forms of interaction and cooperation in monitoring and control tasks are leading to new requirements for skilled workers.

These three theses date back to first considerations made by Windelband/Spöttl (2012) within the framework of a research project on present and future qualification requirements set by the "Internet of Things" (IoT) in the field of logistics.

The scenarios have been taken up by social sciences, work sciences and vocational-educational sciences in the context of surveys into the development of Industry 4.0 in reference to M-M-I as well as the distribution of control and responsibility between technical and human systems, above all in the field of production, and were advanced by further aspects. The work sciences often mention assistance systems that support users with their respective work tasks. This encompasses for example the use of (lightweight) robots that could take over physically strenuous or monotonous work, the use of smart devices for a context-sensitive support of work (cf. Deuse et al. 2018) or for monitoring and controlling of intelligently networked production resources (cf. Schlund/Gerlach 2013). The Man-Machine-Collaboration is playing a decisive role for fully taking advantage of the potentials of artificial and human intelligence. According to Traumer et al. (2017), it is necessary to analyze tasks in terms of the required abilities necessary for problem solving in order to select the "correct" kind and way of collaboration (Man-Man, Man-Machine, Machine-Man). This decision should consider the development of the most resource-friendly and at the same time socially desirable collaboration that should adhere to existing norms and legal stipulations. This should form the basis for the development of collaborative work practices at the Man-Machine-Interface (e.g. during the development of collaborative robot systems) in order to safeguard human-centered and humane work and to comply with the use of the strengths of both human beings and machines.

The dependence and the interrelationship between technology, organization, and the workforce in the context of assistance systems in Industry 4.0 are manifold and depend on different influence factors such as legal framework conditions, participation rights, or safety requirements/data protection. It becomes apparent that along with the progressive automation and an increasing complexity of the systems only limited controllability of technology remains, accompanied by a highly functional and economic failure potential and incalculable requirements for acting at work (Hirsch-Kreinsen 2016). The research on automation has coined this development the "ironies of automation": Due to their high routine character in case of malfunctions, automated processes often generate work situations that are difficult to cope with (Bainbridge 1983). According to work-sociological surveys, ways of action such as intuition and sense but also experiential knowledge about the operation of complex plans are crucial. This is called "Subjectivating acting at work" (cf. Böhle 2013). Mastering complexity in an increasingly networked world of work will be a great challenge in the future. Due to further networking and thus the opening of the systems within the entire value-added chain, there is a discrepancy between the data-technological compilation and the analysis and use of data for process optimization on the one hand and the complexity and dynamics of what is really happening on-site on the other hand (cf. Böhle 2017). In order to master these conditions and requirements between the real and the virtual world, uncertainties have to be dealt with and skilled workers must act correctly in unplannable situations (cf. Pfeiffer 2014). This can only be achieved with the ability to acquire new experiences and to apply existing experiences in a new way to react to and cope with unpredictable challenges (ibid. 5). However, the M-M-I must be designed in a way that the operator can still intervene into the system. The more decisions are taken over by computer programs, the more the ability to deal with complex situations and to actively shape the world of work will fade away. Thus, the design leeways of skilled workers and their options to make decisions will be restricted.

Nevertheless, the development and the acquisition of this experiential knowledge can only be successful if skilled workers are adequately qualified and able to make use of this expertise during their work. The solution of problem situations and imponderabilities above all in dealing with virtual environments is in the center of interest and aims at developing vocational experiential knowledge. Life-long vocational learning, the ability and readiness to change, and the handling of imponderabilities can thus be considered the keys to a successful transformation.

3 Challenges for (Vocational) Learning

Thus, the requirement profiles of skilled workers take a different orientation based on the use of Industry 4.0-hardware in plants and a wider networking of work and business processes in companies. Aspects of networking and thinking within networked systems are increasingly playing an important role for skilled workers on the shop-floor-level (Spöttl et al. 2016; Zinke et al. 2017). Increasing automation in production is leading more and more to a change in the vocational tasks of skilled workers: They have to complete their tasks with digitalized tools, operate the production facilities via human-machine interfaces, and develop their professionalism with the help of digitalized media, assistance systems, and cooperative work structures. More and more the ongoing merger of information technological and classical production processes can be observed. The decentralized intelligence within the framework of Industry 4.0 leads to a higher availability of highly process-relevant data, which are analyzed, processed, and worked on by skilled workers for the optimization of work-processes and problem solution (cf. Spöttl et al. 2016; Becker et al. 2022).

The following challenges in the context of developments towards digitalized work can be derived from a study for the M + E (production and mechatronics) sector for skilled work in Germany (Becker et al. 2022, p. 75):

- Overall understanding of production and mechatronics: interface knowledge, interaction of software and production process;
- Process understanding and overview of the complexity of processes: synchronization of processes along product creation;

- Process optimization /ensuring process reliability: variable use of production parameters, problems disruptions;
- Process data, data analysis, and its evaluation: processing order data, recording, and utilizing production parameters;
- Programming (low code) /parameterization tasks: use of application software;
- Data analysis and networking processes: data-supported support of work processes, increasing productivity, networking of production areas;
- Troubleshooting: analysis and elimination of causes of problems (reading live images, evaluating and solving the problem);
- Hybrid task performance: combining traditional tasks and ensuring mechanical, electrical, and information technological functionality.

However, not only production is affected by the development of digitalization. A current study into fourteen different training occupations – from specialists for wastewater technology, industrial managers, up to digital and print media designers– conducted by the German Federal Institute for Vocational Education and Training (BIBB) shows that the "digital" permeation process is taking place at a different pace and indeed differs in terms of depth and rigorousness, also between the surveyed occupations (Zinke 2019). Although digitalization has meanwhile arrived in all of the fourteen surveyed occupations, just "one out of three interviewed skilled workers, trainers, superiors of skilled workers, and persons responsible for in-firm training estimates that the grade of digitalization of the work places in the surveyed occupations is already high." (BIBB 2018) This varying velocity of permeation of digitalization depends on different factors such as the respective business model, the economic framework conditions, the strategies for the introduction of new technologies, the acceptance of technologies by the employees as well as implemented qualification concepts, and last but not least the shaping demands and objectives connected to the implementation. The shaping of future workplaces combining an interaction of man and machine will become of utmost importance.

4 Which Challenges Can Be Derived for Occupational Learning?

Nevertheless, digitalization cannot only be determined by technological development and its changes. Likewise, it is not enough to embed Industry 4.0 technologies into the context of work processes with a focus on a didactical reflection of the shaping of learning processes of initial and further training. Further to a specialist understanding, an understanding of the entire process chain, the organization, and business processes, and the changes of the Man-Machine-Interface have to be established. Thus, the object of vocational education is considerably widened up as both digitalization itself and the changes it has triggered must be seen in a multidimensional way (see Fig. 1).

So far, initial and further training have mainly concentrated on the so-called Industry 4.0-technology and its comprehension and functioning (as for further training issues cf. Richter 2017, p. 242 ff.). Thus, the didactical understanding is predominantly still focused on functionalities or artifacts of digitalization (objects, products, media) (cf. Becker 2019, p. 2).

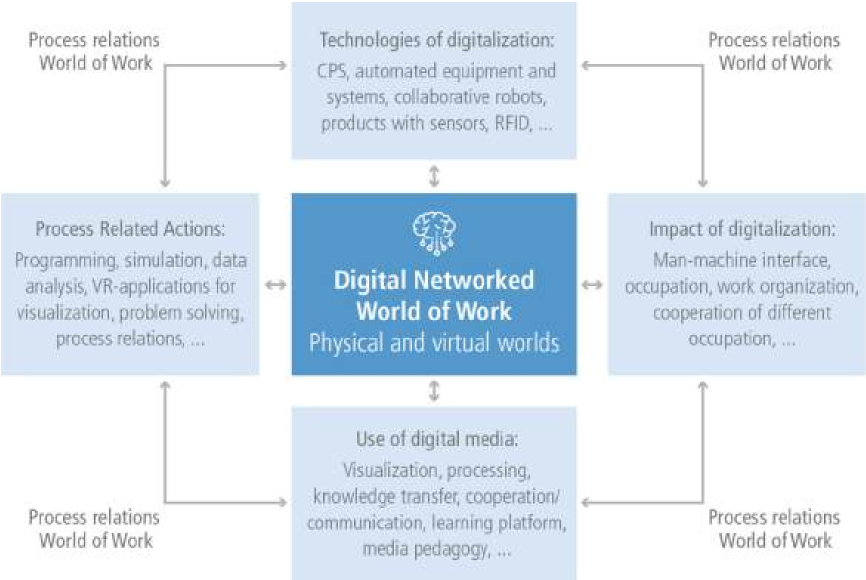

Fig. 1. Digitalization as object of vocational education and training in process related contexts (own illustration)

Above all the process interrelationships, the mastering of interfaces as well as the interaction with specific process data for problem solution are playing an increasingly important role for didactical decisions due to the blending of virtual and physical systems in the world of work (cf. Spöttl et al. 2016, Zinke et al. 2017). This poses central challenges to vocational education, such as (Faßhauer/Windelband 2021, p. 247):

- Working and learning with and within virtual systems (simulations, process visualization, Virtual Reality (VR) applications,
- Work with and at smart plants and processes with Artificial Intelligence (expert systems, diagnostic systems, knowledge management systems, Smart Maintenance),
- Hybrid management of tasks and organization of process structures (hybrid tasks, mixed occupations),
- Work with and handling of data (data compilations, data analyses and transfer, data security),
- Emergence of new Man-Machine interfaces (organization, shaping, control, assistance),
- Interdisciplinary learning and networked cooperation along the value-added chain (occupational didactical concepts across domains, cooperation of different learning environments),
- Learning in real and in virtual environments (digital media, learning management systems, learning tools, learning factories),
- Handling of complexities and unpredictable problem situations as well as thinking in networked systems (system and process understanding, experiential knowledge).

In the sense of a vocational competence to act, this means that concrete learning and work tasks must focus on the presentation of problems in a digitalized world of work rather than on digital tools (e.g. VR glasses or 3-D-printers) or on digital media (e.g. tablets or whiteboards) as such.

5 Changes of Vocational Learning Triggered by New Forms of Learning and New Technologies

Learning in the company is intensifying along with the digitalization of the world of work and enhances the process, the reflection, and learning character of company-based work that has already been practiced in many companies as early as in the 1980s /1990s (Dehnbostel 2019, p. 4). Digital learning can directly link working and learning in the work-process. This is underlined by the growing prevalence of interactive forms of learning and e-learning such as blended learning, webinars, learning platforms, online communities, and mobile and augmented learning as shown in Fig. 2.

Small learning offers such as learning nuggets (94%), learning videos (93%), and blended learning (91%) are seen as digital learning forms in continuing education for the future. In addition to self-determined learning offers, the pure forms of e-learning with Web Based Trainings (WBTs) (71%) or webinars (87%) have shown increased approval since the beginning of the Covid-19 pandemic (Mmb-Trendmonitor 2022, p. 6)[1]. Industry 4.0 is still considered a central driver of corporate further training. The use of simulations such as learning-oriented forms of Augmented Reality (AR)/Virtual Reality (VR) are increasingly gaining importance in vocational education and training, from virtual welding to entire learning factories. Learning in a safe virtual work environment is a great advantage as it is shaped in a flexible, self-regulated and interactive way. Given the fact that the implementation and integration of occupational situations in occupational learning environments are often linked to numerous problems (e.g. high procurement costs, state-of-the-art and complexity of the machine, risk factors due to the work environment), virtual environments can also have methodological advantages (cf. Zinn 2019, p. 22). In virtual learning environments, this experience leeway can be created when the learner interacts with his/her working environment (Haase et al. 2015, p. 193). Learning and working in virtual environments are hazard-free for beginners. There is neither material wear, nor can complex machines/plants be damaged. Practical and process-related learning situations can thus be simulated. At the same time, the learning environment supports collaborative learning and working.

The swift technical progress of VR/AR-technologies opens up more potential fields of application for VR/AR learning applications in vocational education and training. However, these fields of application should always be aiming at the pedagogic and didactical value added rather than focusing on the technological possibilities. With the aid of these new technologies, many new didactical possibilities within vocational education will be generated. However, the aim is to shape completely new teaching and learning processes (Redefinition, Fourth Level) rather than digital media as a substitute

[1] The results are based on an online Delphi survey. A total of 70 experts from the education scene in Germany, Austria and Switzerland were surveyed in 2021.

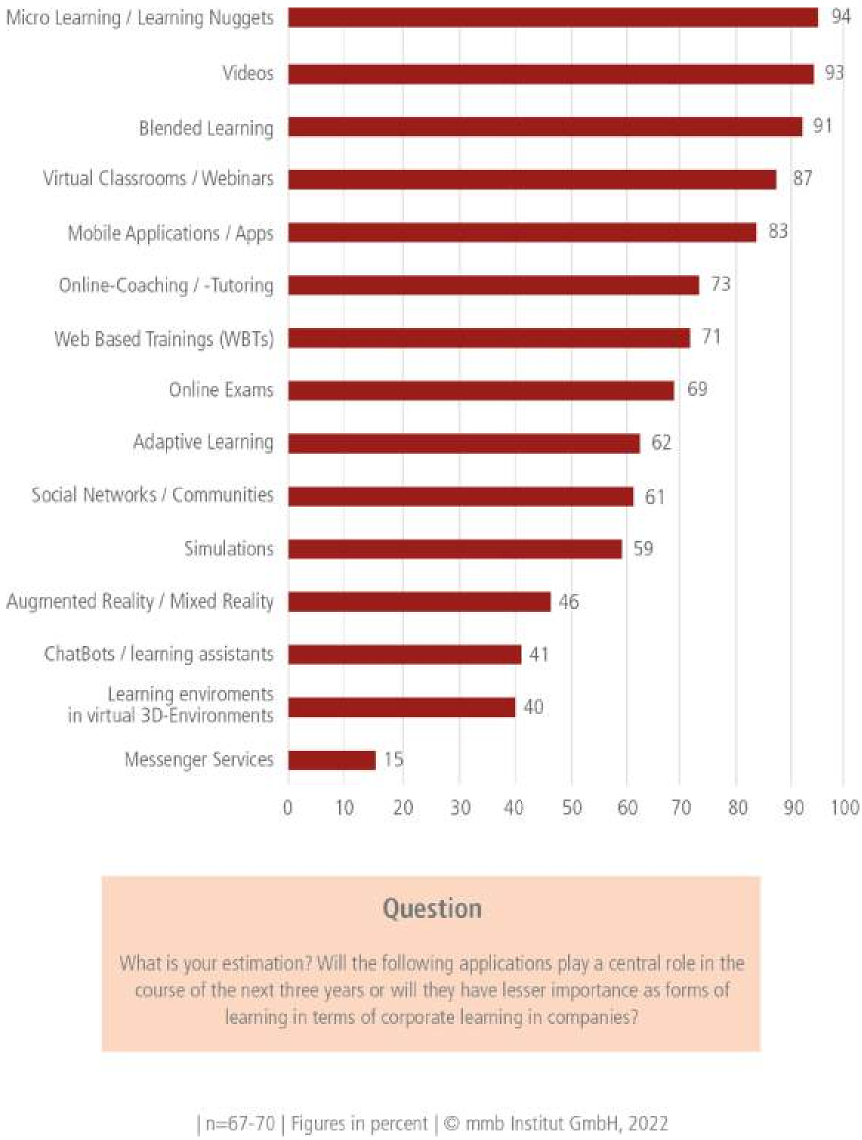

Fig. 2. Importance of applications as forms of learning in companies (own illustration based on mmb-Trendmonitor 2022, p. 6)

for traditional media without functional amendments, such as the e-book substituting the textbook (Substitution, First Level) (cf. SAMR-Model according to Puentedura 2006[2]).

[2] The SAMR model describes how learning has been changing due to the application of technology. The model helps to derive how the shaping and the handling of learning settings with digital media (digital tools) can be improved. With the aid of the model, the educational staff can

An example for the redefinition in the building sector shows the new shaping of learning processes with the aid of an Augmented Reality application. Equipped with AR- glasses, operators of building machines are provided with details on the terrain before them and receive information on the execution of their current work task. During the excavation of a building pit, they are, for example, assisted by graphical information about the depth of the excavation and about the limits of the radius of the excavator arm (Bach 2019, p. 47).

The machine operator of the future not only has all necessary information at hand. He/she can also have all details projected directly to the building terrain in front of him/her with the aid of his/her data glasses – not only in real time but also in 3D" (ABZ 2019). The SAMR-model[3] is based on the presumption that the quality and the pedagogical benefits of the use of digital media will increase with climbing up the various levels (cf. Heinen/Kerres 2015, p. 21). However, this must take into consideration that the effectiveness of media offers depends on various factors, among others on the learners' domain-specific preliminary knowledge and their existing learning strategy, their intelligence as well as their motivation and volition (cf. Helmke 2014, p. 71).

6 Change of Work-Related Learning Triggered by Assistance Systems and Artificial Intelligence

Work-integrated learning – also named learning in the work-process – is increasingly influenced by digital assistance systems. The real functions and the promotion of learning provided by the applied assistance systems or systems of Artificial Intelligence are likely to depend on how the possibilities of support will be used in the respective application case. Adaptive learning and real-time feedback – both based on "Learning Analytics" – will increase the users' acceptance of the assistance systems. Without innovative didactical concepts at the current state-of-the-art research, it will be difficult to implement scientific and workplace-based learning, cooperative and collaborative learning as well as learning motivational approaches for self-reliant, self-regulated learning (cf. Apt et al. 2018, p. 26).

Generally, the technical assistance systems are classified into information assistants, assistance systems and learning assistance systems (see Fig. 3). Steil/Wrede (2019, p. 14) provide the following definitions:

assign, analyze and evaluate their own training offers. However, the model neglects the shaping of learning processes and thus the didactical implementation. Overall, the SAMR model describes a context-free teaching and learning environment with a focus on the learning product (cf. Hamilton/Rosenberg/Akcaoglu 2016).

3 The SAMR model (Puentedura 2006) has been developed to analyze the technological integration of digital media in the classroom. This model attempts to measure the degree of technological integration at four levels ranging from enhancement to transformation of learning: substitution, augmentation, modification, redefinition.

Information Assistants: Systems that process and edit digital data and make them available for the users. They draw on databases or internet resources. However, neither physical assistance is involved nor is the environment directly sensorially perceived.

Assistance Systems: All help functions assisted by computers in everyday situations or during work situations are called Assistance Systems. AMan-Machine-Interface is obligatory.

Learning Assistance System: Designates a part of Artificial Intelligence that generates data for models (machine learning) based on existing example data (experiences) with the help of mathematical rules (algorithms). The AI is the generalization, i.e. the application of the models to new entries or situations.

Fig. 3. Interrelationship of assistance systems and machine learning (source: in the style of Steil/Wrede 2019, p. 15)

Based on providing information on work-related information and learning sequences, digital assistance systems are increasingly able to take over tutorial functions and can thus contribute to learning in the work process. Some examples of characteristics supporting learning are mentioned below (cf. Apt et al. 2018, p. 27).

- Functions for providing further information (e.g. on texts, images, videos, and animations that provide a deeper understanding of work tasks and work situations or reveal alternative ways for solutions and acting),
- Providing feedback for one's own actions and decision making (e.g. with regard to effectivity, efficiency, and movement patterns relevant for health as well as so-far not yet considered implications of decisions made in the past),

- Functions on information and knowledge research/documentation (e.g. knowledge databases and knowledge management).

In terms of learning, there will be new possibilities as well as personalized support within the work process, with concrete handling instructions for assembly, putting into operation, the operation as such, or the maintenance of the plants. Information is supplied on demand. According to the context, the assistance system automatically fades in information. A respective control unit helps the users to make use of the information for their acting. However, this only works as long as the actions are predictable, i.e. without new problem situations or imponderabilities. At the same time, the skilled worker can only make limited use of and provide his/her experiential knowledge. The skilled workers' tasks to handle imponderabilities and to act adequately when it comes to unpredictable situations in an increasingly complex and networked world of work will be more difficult than ever. Therefore, assistance systems have to be further developed in order to facilitate this feedback. Skilled workers must remain able to tap into their occupational experiential knowledge to contribute to the solution of the problem (cf. Diagnostic work with expert systems – Becker/Spöttl/Windelband 2021, p. 45).

Based on Stein/Wrede (2019, p. 16) there are currently two trends dominating in practice. Numerous manufacturers of machines and technical systems are equipping their plants with an increasing number of assistance functions: simulations, virtual-reality animations or data displays, and apps for tablets or smartphones. Here, the individual machine or individual work steps are in the foreground rather than the production and the work process as a whole. Second, a lot of applications concentrate on information assistants for the automatization of simple routine decision making, e.g. in terms of customer queries or the processing of orders.

The question arises whether the role of the employees during the implementation of assistance functions and systems will move in the direction of control and operation, thus impeding the acquisition of competences. Another option could encourage the employees to contribute their competences to work-processes and thus allow for an interaction between skilled workers and technical systems in both directions (cf. Windelband 2014, p. 20). In case of system failures or other unpredictable problem situations, the skilled workers must have exactly these competences.

The next development step will be learning with AI. The so-called learning systems can automatically spot approaches to problem solving in the range of their defined tasks, among others by observing their environment and by deduction of rules. There is stronger and weaker AI. "Strong Artificial Intelligence" refers to a programmed computer that thinks and acts like a human being and could eventually even develop a conscience. "Weak Artificial Intelligence" is geared to solving specific tasks in a previously defined area – and only in this area (VDI 2018).

Two future options will be shown for vocational education:

- By a collection of data generated during the learning process ("Big Data", "Learning Analytics") and with the aid of complex algorithms, learning needs can be identified and individual learning paths could be created.
- "Machine Learning": When the computer optimizes its functions based on past experiences and impulses from the outside world.

Learning platforms and online courses are currently prevailing in the area of vocational education and training. Teaching material such as documents, webinars, learning videos, etc. is placed at the disposal of the users, and so are exercises,/learning tasks, and test items. Problems are solved collectively within cooperation and communication systems. With the aid of learning analytics, data on the learning process could be evaluated by algorithms in order to increase the learning success and to adapt the learning process to the demands of the students and the teachers. Data on the learning process (learning materials, conducted exercises, necessary time, number of repetitions), indicators for learning success (points acquired with a test or result of problem solving) as well as characteristics of the learners as such (learning type, cooperation type and communication type, demographic characteristics) are analyzed, compared to each other and automatically evaluated (cf. Rubel/Jones 2016). The analysis of these data allows an individualization of learning settings and a more timely identification of learning problems which could e.g. avoid the dropout of participants of a further training measure.

Another option for the use of Artificial Intelligence in vocational education is the further development of adaptive learning systems. With the use of Artificial Intelligence, these systems are gaining further importance, as the evaluation of data and the adaptation of the learning environment and the learning processes are taking place in real time. As a consequence, the learning system can be adapted even more rapidly to the needs and the learners' level of knowledge (cf. Seufert et al. 2020). Meier (2019) describes three models which are central for the function of adaptive learning environments: 1) The domain model with information about learning objects, 2) the learners' model with information about the level of knowledge as well as 3) the tutorial model with information on learning paths.

The widespread various learning management systems can be amended by AI-based functions in order to contribute to a better handling of contents and learning resources by curation[4] (cf. Seufert et al. 2020; Wentworth/Powell 2019):

- Automated key wording,
- Improved classification and organization of learning resources based on algorithms of natural language processing,
- Efficient search (e.g. full-text search in videos),
- Less effort with the reprocessing of learning resources,
- Identification of thematically related learning resources,
- Automatization of administrative tasks, e.g. assignment of learning resources to trainees/learners based on competence profiles and automated context indexation.

In the field of rhetoric and linguistic abilities, first options of Artificial Intelligence allow a reflection of customers and product presentations – also in terms of Virtual Reality applications. These opportunities could also be applied by trainers/coaches as a feedback on the use of fillers, eye contact, speaking rates or body language. At the same time disruptive factors such as interjections or smart phone noises can be added

[4] In the language of IT-experts, curation stands for anything contributing to the processing of knowledge – i.e. researching, selecting, assigning, summarizing, evaluation and networking of information (Source: https://qurator.ai/projekt/).

in order to change the level of difficulties (EasySpeech 2020). The further development for concrete occupational acting situations in the context of customer advisory service (simulation of service conversations) or sales (simulation of sale situations) could offer a lot of potential for initial and further training.

Thus Learning Analytics would offer a variety of opportunities for occupational education although the current data processing methods are still full of risks. Only a few and unbalanced (further training) data are yet available for analyses (cf. Dressel/Farid 2018). At the same time the forecasts are still inaccurate as they are only based on competence-based parameters without taking into consideration the learning process and its framework conditions (cf. Köchling/Riazy 2019). This can quickly result in a discrimination of this learning type or person as soon as he/she deviates from the given learning structure. Various questions of data protection (among others consent to handle personal data, data identification, data processing and data saving) must be clarified prior to making use of the option of algorithmic data processing.

The use of artificial intelligence for further education can also lead to a higher fit between supply and demand as well as reduce the time-consuming process of searching for offers. The first platforms for personnel development and AI-based learning already exist for the metal and electrical industry. Based on the qualifications of the employees, development goals and possible qualification paths are shown. Algorithms then compare the specifications (qualification needs) in a database of different training providers to determine suitable offers and compile individual programs. The accuracy of fit will continue to grow with the amount of data and the integration of as many training providers as possible (Becker/Windelband 2021, p. 38).

While Learning Analytics have not yet been widely implemented in the field of vocational education, Machine Learning is already emerging in some companies in terms of machines and plants. An example is the proactive maintenance which identifies and monitors the state of wear in components. Sensor data provide information on the condition of machines/processes during their entire lifetime. In the course of time, an exact image of the condition of the machine/plant is building up which can be compared with other machines/plants. Machine Learning algorithms can then be trained with the aid of these data sets on conditions. The Machine Learning algorithms scan this abundance of data for patterns of malfunctions or even a possible breakdown of components (cf. Tidemann 2019). With the aid of the data sets of conditions, Machine Learning algorithms can be trained. They then look for patterns which hint at malfunctions or to a possible breakdown of parts (cf. Tidemann 2019). Predictive Maintenance makes use of data collected by Condition Monitoring in order to forecast future conditions of a machine and to support the planning of maintenance measures. Skilled workers then receive information about the condition of the machine by providing data generated from automated condition monitoring of plant conditions. These data could then support the skilled worker in trouble shooting, by identification of damage symptoms of plants and possible causes for malfunctions (Windelband/Dworschak 2018, p. 77).

Another user scenario is optical quality control which is already applied in a number of companies, e.g. for the identification of spare parts, the differentiation between “good” and “bad” parts, the identification of anomalies or more generally to determine the quality of a manufactured part. The company Festo Didaktik, for example, is working on the integration of Artificial Intelligence in learning companies[5] for further training in the field of vocational education. The image classification has been chosen as an access to the issue. The included software guides the user across the typical production steps, starting with the generation, the saving and preconditioning of relevant data, the choice and the training of an appropriate AI-process up to the use of the application as such (Schubert 2020). According to the user (developer, end user) the case examples must be offered in a didactically reduced way.

Mastering the complexity of these systems is the biggest challenge. This multitude of data must be correctly interpreted and evaluated. The Man-Machine-Interface will play a decisive role. How will decisions be made on which base? In terms of maintenance, skilled workers are trying to base their decision making on their experience and make use of intuition, senses, feel, and certain process data. What remains open is how the support of the skilled workers will look like as soon as Machine Learning will be governing automated machine supervision and which opportunities of intervention will remain at the discretion of human beings. In the light of these increasingly automated systems the question arises: Will it be possible for humans to build up expert knowledge in order to identify malfunctions and possible solutions in decisive situations, above all when Machine Learning cannot find any solutions? At the same time, skilled workers must learn how to analyze, evaluate and process these data according to their occupational training profession (cf. chapter on consequences).

7 Opportunities and Risks of Artificial Intelligence for Vocational Education

It is still very difficult to estimate the exact opportunities and risks for vocational education due to the fact that the development of Artificial Intelligence is still “in its infancy” in the context of vocational learning (Table 1).

The following points illustrate the potentials and risks for vocational education.

[5] The learning company is a learning environment, which resembles an industrial laboratory and is equipped for industrial problem solving in automation. It is meant to offer a practice-oriented preparation for work in complex and networked production processes. Real work pieces are manufactured in learning companies, starting from the first designs up to production along the entire valued-added process (Windelband 2019, p. 34).

Table 1. Overall definition of AI-influenced autonomy-steps in industrial production (Source: Plattform I40 2019, p. 14).

Step 0	*No autonomy:* The human being is in full control without assistance
Step 1	*Assistance with selected functions:* The human being is always responsible and makes all decisions
Step 2	*Part-time autonomy in clearly defined fields of work:* The human being is always responsible and determines (partial) goals
Step 3	*Delimited autonomy in larger partial areas:* System warns in case of problems, human being confirms suggested solution offered by the systems and functions as fallback level
Step 4	*The system works autonomously and adaptively within determined limits of the system:* The human being can supervise or react in case of emergency situations
Step 5	*Autonomous operation in all areas*, also in cooperation and in case of changing system limits. Human beings can be absent

7.1 AI Supports the Handling of Complexity

The handling of complexity is one of the challenges in the age of digitalization. This is where AI can offer support (see step 1 as well as step 2 above[6]) by evaluating all available data and by providing skilled workers with information on current conditions and forecasted developments. Intelligent machines, plants and networked business processes point out the different program options and the respective effects. With the aid of this option, the skilled worker is able to make decisions and to find problem solutions in interaction with technology (Assistance Scenario cf. Windelband/Spöttl 2012).

Step 3 forms the bridge between assistance and automation: Human beings confirm certain strategies for solutions or support them in case of specific problems. This step stands for a delimited autonomy in larger partial areas. The system warns autonomously in case of problems (cf. Plattform I40 2019).

On the highest autonomy step (Step 5) of Artificial Intelligence (ibid., p. 18), the operation of a plant or a comprehensive production process should run completely autonomously. The system works out self-organized solutions. While the human being still has supervising functions in step 4 and can interfere if the need arises, this is no longer intended in step 5. Here, the Artificial Intelligence makes all decisions autonomously (Automatization Scenario, cf. Windelband/Spöttl 2012). Steps 4 and 5 would lead to a serious loss of work places, above all on skilled worker level. If all decisions were taken over by Artificial Intelligence, the ability of skilled workers to handle complex situations would fade away. Thus, the question arises what would happen in case a problem cannot be solved by Artificial Intelligence.

7.2 AI Supports Corporate Learning and Creates a Learning-Supporting Work Environment

In the future, data on vocational learning could be evaluated with the aid of learning analytics and algorithms in order to enhance the learning success. The projected evaluations could thus be enhanced with learning information or simulated in virtual environments as training scenarios (cf. Peissner et al. 2019, p. 11). At the same time, the data could be

[6] Overall Definition of AI-influenced autonomy-steps in Industrial Production (Plattform I40 2019, p. 14).

used to identify early terminations. Learning offers could be better tailored to the needs of the target groups who could then learn more individually[7]. However, this can only be successful when AI systems are shaped in a learning supportive way. Sensitive data must not be used to the detriment of the individual learners.

A learning-supportive work environment is the basic prerequisite for a sustainable development of competence and consequently for the creation of continuous improvement processes. Skilled workers in working environments using AI must be granted a leeway to participate in decision-making or to make their choice between alternative decisions. Competences for the analysis, the processing and the interpretation of data will become increasingly important for skilled workers. A learning-supportive work environment needs room for problematic and thus learning-supportive tasks.

With the aid of AI-based assistance systems, it is possible to train low-skilled persons in the handling of more complex work tasks. They are supported during their processing of work tasks. The quality of the work results can thus be increased. New target groups (semi-skilled and unskilled, refugees without vocational training) could be qualified for vocational training. A decreasing number of more complex tasks in the companies due to their use of AI systems (steps 3 to 5) could result in a predatory competition among semi-skilled personnel on skilled worker level.

7.3 AI Creates and Destroys Work Places

With the introduction of AI-systems on steps 4 and 5, it is most likely that work places on the skilled worker level will disappear. On the other hand, the implementation of AI assistance systems in all branches will create new workplaces, above all during the development and the implementation of AI-systems. At the same time, these AI-systems must be implemented, operated, and maintained.

Concrete forecasts are currently scarce. A study by the German Institute for Employment Research (IAB) and the German Federal Institute for Vocational Education and Training (BIBB) shows the impact of digitalization in a differentiated way. According to the study, the manufacturing industry will probably witness the heaviest loss in employment due to digitalization. Around 130,000 workplaces are likely to be lost. On the other hand, the study expects that the sector “information and communication” could probably be the winner in terms of employment with a forecasted 120,000 additional workplaces (Zika et al. 2018). The current study “Automation, Skills Use and Training” conducted by the Organization for Economic Cooperation and Development (OECD) fears that 14% of all jobs could be lost in the future due to the fact that robots or algorithms are taking over the tasks. Another 32% of occupational profiles in the OECD Member States would witness a radical change (Pouliakas 2018). The highest substitutability potentials are still found in manufacturing occupations (almost 84% of jobs could be automated); the lowest in social and cultural service occupations. 34% of employees paying social insurance contributions are carrying out tasks that could someday be replaced by robots or algorithms. In 2018, this figure was at 25%. This is the result of a study by Dengler/Matthes, published in 2021.

[7] As early as in the 1980s, Bloom (1984) has already shown that learners who were individually supervised 1:1 with tutors showed better results in exams than learners in conventional learning arrangements (frontal-oriented learning settings).

8 Consequences for Vocational Education

The already existing qualification structures and – in the long term – also (almost) all occupational profiles are considerably influenced by changes in the world of work due to digitalization and Artificial Intelligence. At present, the direction of development and a forecast on the necessary competence profiles cannot always be further described.

Digitalization partly creates brand new training occupations such as commercial clerks for e-commerce, a training occupation across all sectors dealing especially with online trade. At the same time, more and more vocational occupations with hybrid structures will probably be needed (cf. Becker et al. 2022). Forecasts are currently very difficult to formulate. A lot will depend on the future shaping of work- and business processes. Interrelationships between the increasing technization of work with assistance and AI-systems, the changed organization processes, the workload as well as the self- or other-directed possibilities for action will be decisive.

Most of the current occupations on skilled-worker level are currently not in danger to be lost – on the contrary: Some occupations are even experiencing an upgrade because routine and heavily stressing tasks are supported by assistance systems. In addition, more qualified tasks in terms of diagnosis, analysis and evaluation of (process) data have been added to the occupational profile. This may lead to an increase of attraction of skilled work, of the "blue collar workers", as soon as the work places are shaped in a way that all competences and above all experiential knowledge can be brought along. Target groups of young people who are currently aiming to start an academic career could be won for skilled work as workplaces are becoming more and more interesting due to the integration of new media/tools such as tablets, augmented-reality glasses or robots. However, the requirements on the skilled worker level are increasing and include interdisciplinary thinking and acting in networked systems. The implementation of digitalization could be supported by assistance systems and AI-systems. These auxiliary systems must be shaped human-oriented in order to leave the better part of decision making within a company to the employees. This would be an important prerequisite for securing work places in a digitalized world of work.

Occupational learning is increasingly influenced by digital assistance systems. The actual learning support of applied assistance systems or AI-systems will depend on whether and how the skilled workers will still be given the option of intervention and control.

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Designing Digital Work – A Tale of Two Complexities

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Abstract. Digital work is becoming ubiquitous across a range of fields, ranging from production to services. Besides the effects of automation on the job market, it changes job contents and job demands for those holding jobs. Such jobs are characterized by high information load, higher levels of autonomy, performance diversity and growth potential. Respective jobs, tasks and work environments are often characterized with the term complexity. Paradigms, strategies, tools, and practices of work design must keep up with the affordances of so-called complex sociotechnical systems. However, understanding and conceptualization of complexity in work design are still rather superficial. In healthcare, sometimes labeled as a paradigm for complexity, a rising dissatisfaction with this state can be noticed and a lack of progress in patient safety is lamented. Drawing upon systems theory and its variant systems thinking, an integrated approach to work design is sketched out with reference to healthcare. This approach allows for a more systematic treatment of complexity with its two main strategies of complexity reduction and complexity management. Finally, the transfer of this approach into teaching is discussed within the field of work & organizational psychology at a university of applied science.

Keywords: Complexity · Socio-technical systems · Healthcare · Work design

1 The Rise of Digital Work

The general term "digital work" refers to work activities that are largely based on a digital infrastructure, are integrated into it, or require the use of digital tools in core areas of value creation. Key technologies are sometimes identified as drivers of digital work. The World Economic Forum (WEF 2018, pp. 5–6) identifies four technological drivers:

- Robotics
- Mobile/Social Media
- Internet of Things/Connected Devices
- Cognitive Technologies (Artificial Intelligence and Big Data Analytics)

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Digital work is found in both the production and service sectors where the mentioned technologies offer different significance and distribution. Broadly speaking, it can be said that the digitalization of work evolves essentially around the integration of the internet with its integrated technologies in value creation processes. In addition to changes in existing tasks, new job profiles and occupations are emerging as well. As in earlier transformation processes (e.g. Womack et al. 1991), work is not distinctively determined by these technologies. Rather, different scenarios are forming that concern two central aspects (Gartzen-Wiegand et al. 2021): The automation of work through the use of technologies and the decision regarding human leadership versus mechanical guidance in digitized work processes.

The automation potential of digital technologies has been studied scientifically for some time (e.g. Autor et al. 2003), but particularly became the focus of public attention in politics and the media with the methodologically innovative publication by Frey and Osborne (2013). The authors studied the existing potential of digital technologies to substitute human labour and estimated it at 47 percent of all labour activities in the US. The focus is not on actual substitution, but rather on the available substitution potential at a certain point in time or within a certain period of time. This forecast led to intensive debates and a sustained discussion, especially among labour market researchers regarding the "potential for substitution" of digital technologies.

For example, in Germany, the Institute for Labour Market and Employment Research of the state-run Federal Employment Agency publishes regular studies and follow-ups on the topic (e.g. Dengler and Matthes 2021). This shows an ongoing dynamic, as new technologies continue to become marketable and thus have to be added to the potential. According to this latest study, the share of employees working in an occupation with a high substitutability potential is now around 34%, compared to 25% in 2016. The potential is considered "high" if at least 70% of the activities in the occupation are potentially substitutable. Dengler & Matthes conclude that even "more complex activities ... can be increasingly automated" (ibid, p. 1).

It can therefore be said that a considerable and increasing proportion of existing activities within occupations can be automated disregarding those occupations and activities where digitization is fundamentally impossible or undesirable. Nevertheless, occupations and activities remain that are digitized, and the question arises of what role man and machine in the respective work hold. Machine guidance is given when the collection of information for the execution of a task is determined by a machine, the solution path is predetermined, and decisions are made automatically. An example of this would be the repair of machines, where the diagnostic data must be partially entered manually by the human and the actual repair must then be carried out by a person according to specifications, while everything else lies within the machine. This can lead to de-skilling of job holders if comparatively demanding tasks that were previously the responsibility of humans are now being automated.

However, it is just as possible that this creates access to work for low-skilled workers who would otherwise have found it difficult to enter the labour market. On the other hand, human guidance is given when the selection of the relevant information sources as well as the final decision on which solution path to take lies within the human being and the machine functions as support. An example of this is a digital dashboard for the presentation of (real-time) information on an issue, the information selection of which is freely configurable by the user, within certain limits. Gartzen-Wiegand et al. (2021) evaluated existing publications on human-machine interaction scenarios and came to the conclusion that human guidance can be found at all skill levels, from assistants to experts, but is more likely to be expected with increasing skill levels.

Exclusively those activities, in which humans take the leading role, are considered digital work in this article. Equipped with digital technologies, but in the leading role over the machine, these activities are characterized by a fourfold "unleashing" compared to pre-digitalization:

- Information: Rapid access to a wide range of information, its storage, filtering and visualization, statistical processing and simulation options for trends multiply the amount of information available at any given moment and can also significantly improve the quality of information, for example through sensor technology and automatic processing of information. After a work environment with as little of already standardised information as possible, we are now entering a working world characterised by information overload.
- Autonomy: Comprehensive information in connection with sufficient qualification enable us to make decisions on the spot and thus avoid lengthy and error-prone processing procedures. This requires suitable scope for action and decision-making, specifically the allocation of corresponding competences to the persons carrying out the tasks. Through digital networking, their decisions can also have significantly more far-reaching effects on other, even more distant areas in their own organisation or other organisations.
- Performance diversity: such work activities allow the use of a wide range of individual skills. Individuals differ not only in cognitive abilities, but also in personality traits such as creativity, openness, or conscientiousness. In work activities with multiple sources of information and high levels of autonomy, these differences mean that performance can no longer be considered normally distributed across different job holders. This leads to a curve more reminiscent of the Pareto distribution instead of the symmetrical distribution of performance around the mean. Here, most jobholders are similar in their performance, while a few individuals exhibit a far greater performance (Mühlbradt 2020).
- Growth: Digital value creation processes, especially in the field of immaterial services, operate at least partially with available technical infrastructures free of charge, open-source solutions and inexpensive devices. Large investments are no longer necessarily dependent for high level technology in order to enable innovation and a high degree of utilization. Building on this, these processes have an enormous growth potential. Taking the freight carrier business as an example, if the process of daily routeing of the trucks could be automated via artificial intelligence (AI) so that time for human planning decreases from hours to seconds, more human capacities would be available elsewhere. Therefore, there would be no reason why this capability should not be made available via internet for thousands of freight carriers.

The following discussion demonstrates that our capabilities to design unleashed digital work with the dynamics of change need to keep up with the time. This requires a new way of thinking that is closely linked to our understanding of complexity and how we deal with it.

2 Complex Sociotechnical Systems

Groundwork on systems theory has been published by Bertalanffy (e.g. Bertalanffy, 1940), a highly influential modern theory. Although some of the roots go much deeper (Lutterer, 2021), this consideration focuses on this work. Likewise, we will not go into the numerous perspectives and applications of systems theory but limit ourselves to the field of work analysis and design. This refers essentially to the disciplines of work science and work management, work and organisational psychology, industrial sociology, and the interdisciplinary field of human factors. Today, we usually speak of "work systems" in these mentioned disciplines.

In general a "system" consists of several interacting elements. Systems figure before a background called environment. Systems are partially open and interact with their environment through a boundary. Furthermore, they are self-regulating and based on feedback. This abstract concept of a system is suitable for any sections of reality that makes it a meta- or universal theory for application in different sciences and realms of reality. Figure 1 shows the two standard views of an abstract system.

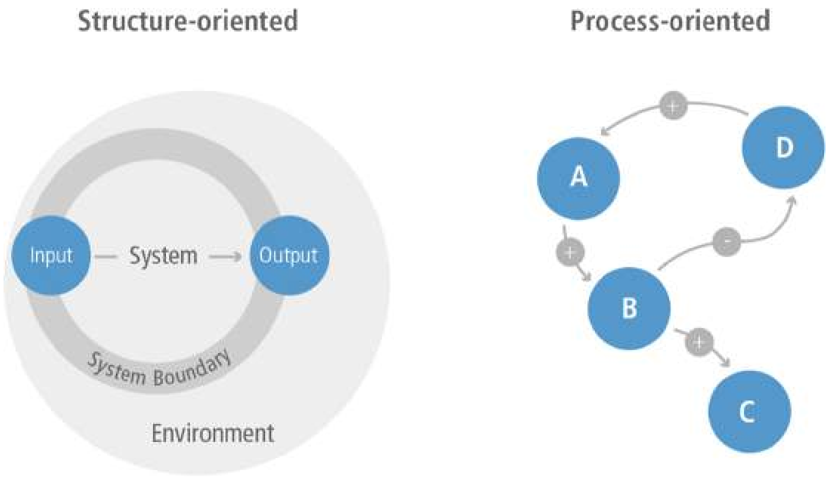

Fig. 1. Two views of abstract systems

The left illustration shows a frequently encountered representation (e.g. Schlick et al. 2018, p. 22). A system interacts via input and output with its environment, from which it is separated by a partially permeable boundary. Subsystems or elements within the system can be connected to each other via relations. The emphasis is on the structural side and is therefore often selected to represent objects "systematically".

Quite different, but completely equivalent, is the representation of a system as a chain of elements acting on each other, so forming a process. The system in the right illustration consists of the elements A-D. Everything else belongs to the system environment, which one has to imagine as an amorphous background (e.g. Senge 1990, p. 97). The focus is clearly on the process, where the elements can be concrete activities, for example a number of activities as in making coffee. However, they can also be impact factors or states. This form of representation is particularly suitable for constructing models to explain phenomena.

A "systemic" approach focuses not on isolated elements, but instead on the system as a whole. Thus, the concept of "emergence" refers to a class of phenomena (e.g. system properties or actions) that are caused excessively by an interaction of elements that ultimately cannot be clearly determined, in accordance with Aristoteles expression "the whole is more than the sum of its parts". Admittedly, the system can be broken down into parts, however, this just does not explain the emergent phenomenon in question.

Applying the concept of systems to human work in connection with technology, an evolution of the understanding and conceptualization of systems can be demonstrated. For the production and use of simple tools, it is sufficient to consider the object itself.

The use of machines as technical entity with moving parts and propulsion systems does not represent qualitative changes as long as the propulsion can be rendered through draft animals, wind energy and hydrodynamic power. The design of technology remains relatively unproblematic if these machines do not provide large amounts of energy and thus cannot deliver high velocities. This changed with steam power, the internal combustion engine, and the electric motor in combination with further technical inventions. Power, velocity, and risks far beyond the usual "human scale" made a broader perspective necessary. A leap of innovation in this regard was initiated by the Second World War. For example, the speed of an aircraft increased by 300 percent and the number of controls and instruments in the cockpit by 350 percent (Badke-Schaub et al. 2012, p. 5). Considering this background, Hollnagel (2021) sees the advent of the man-machine system (MMS) concept around 1945. Under the impression of increasing technical possibilities, the MMS became a concept and object of design. The concept is that both elements - man and machine - must be considered in their mutual relationship so that the totality of both can operate successfully.

A little later, under the influence of a field study in British coal mining, the concept of the "socio-technical system" (STS) emerged (Trist and Bamforth 1951). After a change in the technical method of coal extraction in a mining company changes in tasks as well as responsibilities were experienced as deskilling by the miners. The concept of STS extended the human component of the MMS from individuals to teams and demanded a conscious design of the social subsystem as well as the joint optimization of the technical and social subsystem. This insight triggered a continuing preoccupation with work organization in occupational psychology (Ulich 2011), industrial sociology (Hirsch-Kreinsen 2014), and labour science (Heeg 1991). In these days, the term STS was almost considered a conceptual common good, which has become an integral part in the concept of Industry 4.0 in Germany (Kagermann et al. 2013).

With increasing frequency and not just recently, work systems have been associated with the term "complexity" or the adjective "complex". The following statements cover a period of about 40 years from the "Ironies of Automation" (Bainbridge 1983) to the WHO's Patient Safety Action Plan (2021), without claiming to be - even approximately

- complete. The definition of "complex systems" range from a self-evident term that does not even need to be explained (Grote and Kolbe 2015) to a particular discussion of the term complexity (Jenkins et al. 2009; Latos et al. 2017; Patriarca 2021). Different, sometimes interwoven, views of complexity can be found.

One view is the complexity as a property of a system (Latos et al. 2017), while process complexity (Bainbridge 1983; acatech 2016) is considered a linguistic variant of this. Jenkins et al. (2009) gave their work on the methodology of work analysis with the significant title: "Cognitive Work Analysis: Coping with Complexity" and considered the complexity of systems to be gradual. As essential properties of complex systems they looked at system dynamics, the number of components and relations, the predictability of future system states and the extent of risks through actions.

Another point of view focuses on the environmental complexity faced by work systems (e.g. Walker 2015; Meissner and Heike 2019) or "real world complexity" (Dekker et al. 2008).

The WHO uses a combined perspective in the Global Patient Safety Action Plan (WHO 2021). In it, the healthcare system is described as: "complex amalgam of actions and interactions, processes, team relationships, communications, human behaviour, technology, organizational culture, rules and policies, as well as the nature of the operating environment" (WHO 2021, p. 2).

Another perspective arises from Schaper (2015), he speaks of "highly complex services" that are being provided in the health care sector. This corresponds to complexity as task complexity. A comparable view is employed in Norman (1986) concerning the use of devices.

In summary, complexity is understood as a property of the system, the environment, the output, or all of these together. This status quo is to be criticized in two respects. First, there is a confusion regarding complexity and complicatedness: a large number of interacting parts is not complex if this does not play a role or poses a risk. On the other hand, Norman (1986) mentioned a vivid example in his introduction where novice sailors were already overwhelmed when performing using a single parameter (steering a sailing ship according to a compass). Secondly, the relationship between objective and subjective complexity is unclear. Is complexity objectively present, or is it experienced differently between individuals? Patriarca (2021), for example, concludes that complex systems are those that are never fully understandable ("knowable") and states regarding the resilience engineering approach: "complexity is not considered a thing per se, rather it is a situation to be investigated" (ibid, p. 479).

Latos et al. (2017) also point out that human perception of complexity is also subjective. Norman (1986, p. 33) analyses the concept of task complexity and concludes: "the correct conceptual model can transform confusing, difficult tasks into simple straightforward ones". This anecdotal sequence is complemented by a systematic literature review of long-term trends in research on socio-technical systems (Mühlbradt et al. 2022). The analysis was part of the session 'Current approaches to the analysis of complex socio-technical systems' at the Spring Congress 2022 of the German Society of Ergonomics. The aim was to systematically display research trends considering methods and designs of socio-technical systems based on the date of publication using SCOPUS literature database. Articles were included that contained a combination of the words socio-technical and system/approach/design/method/analysis in German or English in the title, abstract or keywords. 5,664 publications from 1967 until 2022 were found. In addition to thematic clusters, three hypothetical trends alongside the increase in complexity of sociotechnical systems emerged (Fig. 2).

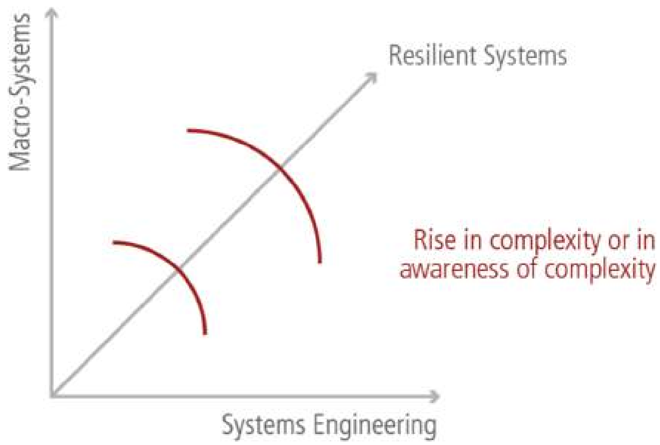

Fig. 2. Hypothetical trends based on the literature review (Mühlbradt et al. 2022)

The authors found a development in publications that increasingly refer to the term "complexity" and either postulate an increase in complexity or argue for a stronger awareness of already existing complexity in procedures and methods. Three focus areas can be identified in this development:

- Designing frameworks and sophisticated methodologies for designing IT and/or work systems under the heading "systems engineering" (e.g. Leveson 2012).
- The resilient organisation as a mission of socio-technical design with a focus on the health care sector (e.g. Hollnagel 2018).
- Transfer of socio-technical approaches to regional and substantial societal macro-systems (transport, urban planning, etc.) far beyond work systems (e.g. Gebhardt and König 2019).

Since Bainbridge already discussed the effects of complexity in the context of work systems in 1983, publications on this can be found continuously and one could initially assume that this has always been an aspect of work systems. In this respect, it is possible that individual differences can be found. In this case, the individual inability to understand a system (an environment, a task) should be remedied by human resource management measures such as personnel selection or personnel development.

However, if complexity is present for most or all people in the system, this strategy fails. It is argued here that the factors

- digitization of work
- unleashing of work
- increasing demands on performance and efficiency of processes
- increasing regulation

come together and lead to more and more work systems, tasks, processes, or environments that can be perceived as complex. The phenomenon of complexity is thus changing from an exception that affects a few individuals towards the fact that it affects many or all people concerned (employees, manager, customer, partner). This on the other hand leads to a crisis of work design, as will be argued in the next section.

3 A Crisis of Work System Design

Work systems change with their requirements and the available technical possibilities. With them, paradigms and methods of work system design must change, as already stated above. The question arises whether methods for designing complex socio-technical systems are available and how good these methods are. For a closer inspection concerning this question, the health care system is a good place to start. This is because, according to the WHO, it is a "complex amalgam" (WHO, 2021, p. 2), or, in the words of Braithwaite et al. (2017, p. vii): "many people believe that healthcare is the example par excellence of a complex adaptive system". Within healthcare the focus of work analysis and design is often on the criteria of patient safety, the prospective avoidance of possible errors and the analysis of past errors. This can be considered a special case of work analysis and design.

Braithwaite et al. (2015) claimed that healthcare is more complex than linear methods of find-and-fix error analysis would allow and judge: "We have to acknowledge the intricacies and complexity of healthcare to overcome this limitation" (ibid, p. 419).

Schrappe (2018) reflected on the improvements achieved in patient safety in Germany with reference to the guiding publication "To Err Is Human" (Kohn et al. 2000). He aimed to make reliable quantitative statements and concluded that a range of 400,000–800,000 adverse events happen in hospitalized patients including an avoidable mortality rate of 20,000 patients annually. Considering these numbers, he called for a revision of "cherished views" (op. cit., p. 353). The concepts of complexity and complex systems play a particularly decisive role (op. cit., p. 7).

Wears and Sutcliffe (2019) also find that too little progress has occurred within the past 20 years. They blame the inefficiency of safety efforts and demand a radical reform.

A bibliometric analysis on the occasion of the twentieth anniversary of "To Err Is Human" for the time period of 2000–2019 was conducted by Pierre et al. (2022) that included approximately 20,000 publications that referred to "To Err Is Human". The authors concluded that the main emphasis on traditional approaches regarding risk and error management is too excessive and a lack of systemic perspectives exist. Although these systemic perspectives were included in the original publication, they were hardly to be found in subsequent works. The authors are in line with Schrappe, who also lamented the lack of "concepts such as systems or complexity theory" (Schrappe 2018, p. 66).

Furthermore, Sujan et al. (2022) found that actual improvements remain low of expectations and ascribed this to the exclusive use of simplistic and reductionist approaches.

Overall, there is increasing dissatisfaction with the status quo and also with the paradigms and methods of work and process design that are used. An explanation for this dissatisfaction is consistently related to theoretical-conceptual as well as methodological deficiencies. To put it bluntly, the deficits can be interpreted as dead ends in coping with complexity. Particularly, there are four such dead ends:

- Complexity as a feature of something. According to this notion, something is objectively (measurably) complex. A confusion regarding the concept of "complexity" often occurs, which can be understood as a number of elements and their relations that can be expressed by a number. However, all elements and relations of complicated systems are known.
- Decomposition of the system in the analysis until there is no more complexity. This analysis precedes the synthesis, in which the phenomenon of complexity no longer occurs.
- The "Root Cause Analysis" (Badke-Schaub et al. 2012, p. 16) the search for causes of error. The ultimately found cause is isolable by definition from the system and the relationship between the root cause and the revealed error is clear and explicit.
- Systems engineering tries to design and develop methodologies that can handle complexity. However, this also does not lead to a disappearance of complexity, but rather shifts it into the methodology and the interpretation of the results so achieved.

A pause before further argumentation is appropriate at this point. There are two arguments against a crisis in work design; the first argument relates to the problem of complexity.

If important goals such as patient safety are not satisfactorily achieved because of difficulties in analysis and design of complex systems and the work within these complex systems, then why not design simple, linear systems that spare complexity? The answer to this question has already been given by Charles Perrow (1984, p. 89): "we have complex systems because we don't know how to produce the output through linear systems". Linear processes can run stable, efficiently and can be permanently maintained if the environment in which they operate is either simple or has been simplified beforehand by human intervention. The well-known example of a simplified environment is Henry Ford's famous saying that you could have your car any colour you want as long as that colour is black. Our goals and our demands on work systems primarily lead to complexity. There is no other way to generate "complex performance" (see above) when pursuing highly set goals and diverse requirements, than via complex socio-technical systems.

The second argument questions the need for an explicit design of complex work systems. According to this viewpoint, largely autonomous, highly qualified job holders would be able to make the necessary decisions on their own or in a team. Sufficient degrees of freedom at the workplace and available resources would be merely necessary. In fact, there are numerous references in recent work design methodologies regarding employee participation in work design, ranging from lean management (e.g. Bertagnolli 2018) to the design of software tools and user interfaces (e.g. Steimle and Wallach

2022) to setting performance goals for work groups (e.g. Debitz et al. 2012). However, a complete abandonment of work design would ultimately lead to a lot of autonomous subjects that would have to coordinate themselves independently. The costs of this would be high in a digitalized world with multiple networks (Barabasi 2002). To support the individuals in this respect, an organisational framework is helpful. Moreover, the above-mentioned examples of participation-oriented methods do not intend to provide an overall picture of the end of work design. Rather, a permanent change is taking place that involves tasks, forms, and instruments of work design.

Finally, it should be mentioned that the statements regarding the healthcare sector can be generalized. The healthcare sector is a "laboratory of complexity" due to special requirements and framework conditions in which numerous circumstances come together. However, it is by no means an incomparable special case.

In order to get to the bottom of the necessary changes in philosophy and methodology of work analysis and design, it is necessary to temporarily leave the field of work behind and dive into general psychology, or more precisely, into problem-solving research. Here, complexity does not present itself as a property of systems, but as a human experience.

4 Complexity as a Borderline Experience

Borderline experience can be defined as an event that is subjectively experienced as chaotic and exceeds one's own possibilities to create or find transparency and order. Under such circumstances, humans find themself at the limit of their competence to predict and control reality. In Germany, the beginning of a public discussion of systemic effects can be associated with the publications of Frederic Vester (e.g. 1974). Such research often relates to the term "systemic thinking" (Lutterer 2021). In distinction to this, approaches to work design tend to be considered "systemic".

The central idea of systemic thinking is that simple linear causal relationships (A causes B) are often illusory and that it is much more important to assume a multitude of interconnected and mutually influencing factors. Some, or even many, relevant factors and the nature of their connection to other factors (promoting or inhibiting, rapid or delayed effect, etc.) may be unknown at a given point in time. If such hidden side and remote effects cannot be taken into account, implications for operational risks arise.

The field of cognitive psychology investigates thought and cognitive processes in humans. Part of it is since the beginning of the 20th century the study of problem-solving behaviour in humans and animals. The general definition of a problem can be that it is a task that requires the transition of an initial state into a target state whereby the appropriate approach is unknown at the beginning. The distinction between simple and complex problems (Öllinger 2017, p. 590ff) describes a significant differentiation. Simple problems are static, have clear initial and target states and the available options for action ("operators") are basically known. Complex problems, on the other hand, are dynamic (self-changing) and have a large number of interconnected variables (influencing factors) whose effects and interactions are at least partly unknown. The scientific study of such complex problems requires an affordable and effective technical platform, which became available with the personal computer. Therefore, people's engagement with constructed situations was studied in the psychology laboratory soon after (Dörner et al. 1983; Dörner

1989; Funke 2012). In this process, people are exposed to a computer-simulated reality in which they have to act in a goal-oriented manner, although their understanding of this reality is limited and partly flawed. Their task is to achieve certain goals in the simulated reality over a period of several hours. For this purpose, they can intervene in successive game cycles by means of known options, in order to then experience the reaction of the simulation to this intervention and, if necessary, change their strategy as a result. However, the number and linkage of the factors in the simulation is not known at the beginning and must, ideally, be developed independently throughout the course of the simulation cycles. In other words, the test person must solve the problem of absence of knowledge using correct, i. e. goal-oriented, intervention behaviour.

The simulations are semantically associated and assign a role to each participant. Figure 3 shows one aspect of such a simulation. In this case, the participant is an aid worker and has to increase the survival rate and prosperity of local inhabitants in a savannah region. One way to intervene is to drill a well. This increases the amount of available drinking water, which in turn boosts the cattle population and thus contributes to prosperity. The idea of drilling more wells leads to success - a self-reinforcing cycle. However, the groundwater level is another unknown variable hidden in the simulation. It is lowered by the water withdrawal - which has no consequences as long as the level does not fall below a critical threshold. But following, the amount of available drinking water decreases abruptly. Such progressions are typical for exponential functions (see the small box at the bottom).

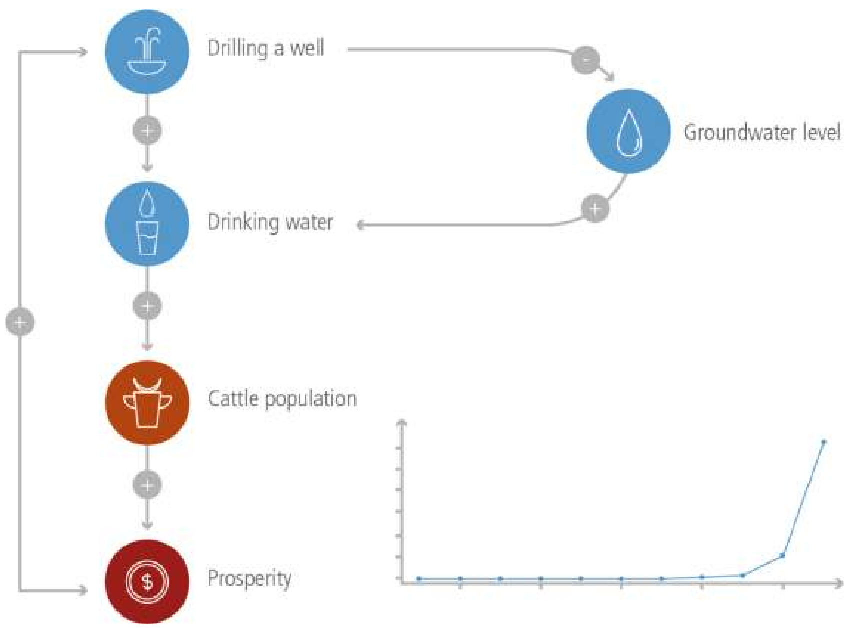

Fig. 3. Knowns and unknowns in a laboratory problem-solving task

In simulated scenarios, participants very often fail to derive and apply an adequate mental model, so that their interventions fail or produce overwhelmingly negative side and remote effects. Consequently, the attempt to achieve the set goals cause frustration and probably an even increasingly worse experience.

Therefore, concerning these simulations one does not like to speak of complexity, the word that comes immediately into mind is "chaos". This ancient Greek word originally denotes a wide empty space or a gap and stands today for complete disorder or confusion. To fight this confusion, no ordering and action-guiding model can be established. The result is either the experience of one's own helplessness or the stubborn insistence on wrong models and strategies. Considering the second case, the eventual collapse of a system will often be explained by factors beyond one's own responsibility.

High-level problem solvers differ less from low-level problem solvers in terms of their intelligence - although, contrary to earlier assumptions, intelligence is also relevant (Leutner 2002; Weise et al. 2020). Dörner (1989), however, finds primarily certain behavioural aspects in high-level problem solvers. They are characterized by advanced levels of information search and integration (i.e. model building), elaboration and balancing of goals, making predictions about developments and a pronounced self-management to deal with stress and frustration.

According to Tatlock's findings (Tetlock and Gardner 2016), high-level problem solvers are:

- open, curious
- self-critical, cautious and humble
- they take nothing for granted, reality is complex for them
- they are good with numbers
- they think in terms of probabilities and are always ready for an update
- they want to improve, and they have "grit"

The best predictor of performance is the degree of willingness to give up personal beliefs and the will to improve. This is about three times more important than the second-best predictor, intelligence. The best laypersons (named "superforecasters" by Tetlock) were superior to experts.

Laboratory and field experiments deliver consistent results to where the interaction of intelligence and behaviour determines the outcome of the experiment. What seems to be decisive in both cases is to be aware of complexity, to presume a lack of knowledge, the need for further hypotheses (models) about reality and the persistent assumption that one could also be wrong. Complexity does not just disappear. However, progress can be made.

5 An Integrative Approach

The fact that complex socio-technical systems are not simply complicated systems cannot be circumvented by methodological techniques, as discussed above. Approaches to eliminate complexity through breakdown and looking at isolated components do not lead anywhere, because they ignore Aristotle's insight that the whole is more than the sum of its parts. However, methods also lead to dead ends that attempt to do justice to complexity through an extensive methodology.

These methods might work in theory, but when practically applied they overwhelm human beings, since the methods and results themselves turn complex. Noticeably the following phenomena take place:

- The methodology is not fully understood or at least not within normal boundaries of time and effort
- The methodology does not produce results in a stringent and objective way but needs creative interpretation of results and imagination

Successful engagement with complex socio-technical systems must consistently integrate the findings of problem-solving research in order to adequately address complexity.

Both traditions must be brought together conceptually and methodologically: "systems" as objective conditions and "systemic thinking" as a subjective level. Particular methods and instruments are used that have such a double system-theoretical orientation within this framework as shown in Fig. 4.

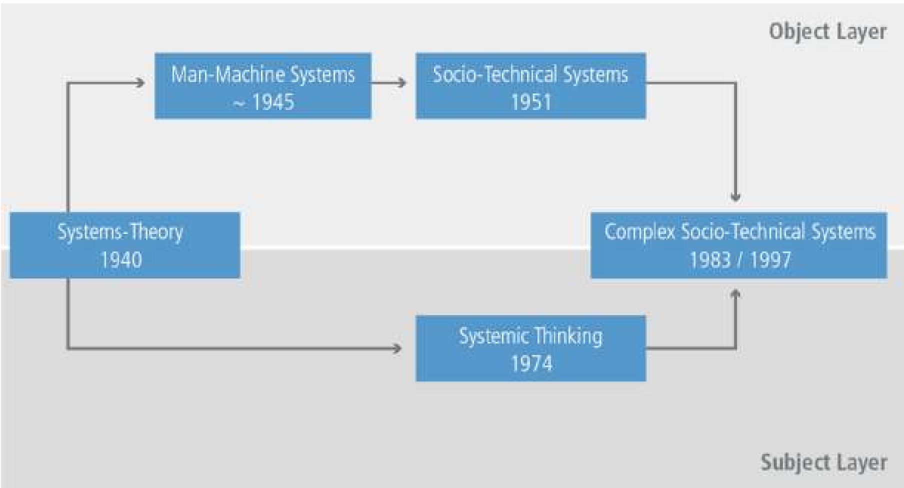

Fig. 4. Integrative system-theoretical approach

If socio-technical systems in work environments are expected to provide "complex services" in an unfiltered "complex environment", then complexity will be experienced by people who act within the system. This relates equally to people working in the system and to people who cooperate with, design, or analyze such systems - there is no fundamental difference between them.

One is almost inclined to speak of virtues regarding the skills identified in psychological experiments. Therefore, the successful and high-level problem solver should also have appropriate competences for people who deal with work systems. And this is always the case when goals and requirements entail complexity. Dörner's laboratory experiments and Tatlock's forecasting studies show that lay people who have a certain level of cognitive capacity and specific virtues such as openness to criticism, a willingness to learn, grit and modesty can achieve very good results and outperform professional experts. There is no reason to assume that this should be different in work systems under the condition of complexity. Any encounter with a living work system in unfiltered (unleashed) circumstances can potentially be characterized by complexity. The study of Bos et al. (2022) is a good example of how fast this can be the case. They performed an investigation in a hospital to find out how a programme for follow-ups of discharged patients was actually implemented by the different departments involved and concluded that the programme was not implemented as planned in any of the cases. The practitioners' process descriptions were more extensive than the planning model and different departments also differed in their practice. Managing complexity successfully starts with acknowledging it.

This integration is not synonymous with the abandonment of all efforts to understand and improve work and organization. However, the claim of complete analysis and design of complex socio-technical systems is very much replaced by the goals of modelling and developing these systems. Dealing with the borderline experience of complexity is not primarily done by applying existing expert knowledge, but rather by a learning process. In other words: The confession of one's own unknowing, the will to understand more and the continued effort to do so, coupled with the ability to be self-critical, are crucial for progress. Within this process, just an improved preliminary result can be achieved, but not a final point.

The integrative approach also does not negate the appropriateness of simple approaches to simple linear systems. Methodologically sophisticated analysis techniques and clearly structured design methods can be suitable means in these cases. The price of a simple system is, if applicable, an artificially simplified environment. The question arises of how high the costs of implementing and maintaining this simplification in relation to the benefits are. A good example of rethinking simplification is the introduction of gain sharing for industrial work systems (Thomas and Olson 1988). Gain sharing assumes that work teams are able to find their own way without prior planning to make their work more efficient so that they achieve certain production goals more easily. If significant and stable improvements are achieved, the teams can then sell these to the company. The company then officially implements them and in return sets a higher performance threshold for premium payments. Turning away from simplification too late is reflected in practices that still work on paper but are undermined in reality (e.g. Siegel 2015). The question arises whether one considers a system to be a simple system only because one has formally classified it that way. Pfeiffer and Suphan (2015) argued that "simple routine work" in industry actually demonstrates a substantial range concerning the level of work contents and demands.

Finally, one should not be deceived by the successes of linear approaches if these successes are based on the sole consideration of selected parameters in a narrow focus, while ignoring potentially negative side and long-distance effects of the implemented measures (Woodnutt 2018).

One might also be tempted to object that the design approach of systems engineering criticized above has impressive successes to show. However, these successes are based on technical structures such as the most recent example of high technology, the James Webb Telescope. It contains many physical components and relations that are certainly very complicated, but not complex. This design task can be mastered with a suitable system, sufficient time, good training, motivation and team strength.

Nevertheless, these systems are not capable of dealing with unknown variables and their interactions and the systemic phenomenon of emergence. The best current approach in the technical direction is that of artificial intelligence research. Their currently dominant solution, the artificial neural networks, achieve their goals through pattern matching with numerous cycles of learning. Delivering a realistic view, Marcus and Davies (2019) ascribe the lack of representation of the world, the absence of causal models, and a "blank slate" view of understanding and learning to these approaches. It is the people who adapt their work to different and dynamic conditions. Therefore, socio-technical systems are still superior and different laws apply to their design.

The integrative approach can be concisely described by a series of axioms. These axioms apply to working persons in "working systems" as well as to their designers:

1. There are no systems in the world - except through us

   "Systems" are arbitrary or deliberate constructions of our mind that we use to better understand the world[1].
2. Nothing is complex - except for us

   Complexity is what we experience when our abilities are overstrained and we therefore cannot fully describe, explain, predict or change something (cf. Winograd and Flores 1995). The statement that something is complex in itself is meaningless. Complexity can only be experienced in the context of a value- and goal-oriented human activity.
3. The ability to deal with complexity varies

   People, teams and whole organisations differ in their ability to deal with complexity. Personality traits as well as thought patterns and behaviour are important for this, but so are team and organisational cultures.
4. Modelling instead of analysing

   Complex systems can be modelled. Complete system analyses of complex systems that resolve complexity, on the other hand, are impossible because:

   a. Elements and states can never be reliably and completely specified
   b. Sufficient resources are never available
   c. If a) and b) does not apply, the results of the analysis would themselves be complex

5. Develop instead of design

   Learning with the assistance of appropriate models can lead to improvements in dealing with complexity. Learning progress enables the generation and the use of more sophisticated models in a sense of "absorptive capacity" (Cohen and Levinthal 1990; Braithwaite et al. 2021).

[1] Every "system" is a figure-ground discrimination in the sense of Gestalt theory (Metzger 1953).

6. "Perrow clause"

   The only reason to design systems that confront us with complexity is that we do not know how we could achieve the same performance with simpler solutions (see Perrow, 1984, p.89).

The concept of the "resilient system" captures a prominent position in the integrative approach. The concept explicitly refers to complex socio-technical systems that are understood as not fully analyzable and predictable (Hollnagel 2016, 2018; WHO 2021). Resilient systems are those that are able to maintain their purposeful functioning under both expected and unexpected conditions. They achieve this by compensating for fluctuations, disturbances, and environmental changes in a situational manner. Approaches to increase resilience are referred to as "resilience engineering". Within this framework, own methods are developed (e.g. Hollnagel et al. 2014) or appropriate methods from other fields are applied, such as planning games and educational games (e.g. Schuh et al. 2020), that help to generate and use mental models.

The resilient system is not as much of a methodological tool in contrast to previous system concepts, it is rather a guiding principle or a model for the development of systems pertaining to the conditions of complexity. Modelling and developing systems can be utilized through theories on factors of resilience (Weick and Sutcliffe 2015; Hollnagel 2018; WHO 2022). In this way, people in the system, at the system and far away from the system can communicate and develop with each other.

In order to meet the requirements of a digitalized world of work with its complex socio-technical systems, the integrative approach presented must be applied. One way to do this can be through industrial and organisational psychology programmes at universities of applied sciences (Mühlbradt 2016), if the universities succeed in strengthening the field of "work and technology" and teach competences needed for dealing with complexity. The following section outlines how this approach is implemented in the training of industrial and organisational psychologists at the FOM University of Applied Sciences in Aachen.

6 Digital Work Design at the FOM Aachen

The FOM University of Applied Science, based in Essen, North Rhine-Westphalia, is a non-profit private educational institution. It is currently the largest (nonvirtual) university in Germany with over 30 locations in Germany and Austria and more than 57,000 enrolled students. Most students have a vocational qualification and initial work experience, they work and therefore study at the university in part-time.

The industrial and organisational psychology department is the second largest department at FOM university with around 10,000 students. This number represents a share of about 10% of all psychology majors in Germany. The Bachelor of Science (7 semester, 180 ECTS credits) and Master of Science (4 semester, 120 ECTS credits) degrees are offered for industrial and organisational psychology at the FOM university. The educational goals of these programmes are formulated as competencies and are further subdivided into professional, methodological, social, and personal competencies. The modules include business administration and psychological content. The Master's programme includes the following modules (Table 1).

Table 1. Programme and modules of the master of science in industrial and organisational psychology with credit points (CP)

1. Semester
• Social Psychology (5 CP) • General & Biological Psychology (7 CP) • Quantitative Research Methods (5 CP) • Decision-oriented Management (6 CP)
2. Semester
• Industrial and Organisational Psychology (6 CP) • Marketing Psychology (6 CP) • Qualitative Research Methods (5 CP)
3. Semester
• Psychological Diagnostics (5 CP) • Elective Module (Independent Research Project) (6 CP) • Human Resources & Organisational Development (5 CP)
4. Semester
• Psychology of Leadership (5 CP) • Psychological Competence (5 CP) • Industrial Organisational Psychology (5 CP) • Thesis (5 CP)

Around 600 students are enrolled at the FOM university in Aachen. The location is characterized, among other things, by its proximity to the large state university (RWTH Aachen) with which joint research projects are carried out. The digitalization of work is one focus of the Aachen location. Within the Master's degree, the study content and forms of work and organisational psychology components are increasingly oriented towards digital work design in a world with complex socio-technical systems. In doing so, references to contemporary research are made. Following, this will be considered in more detail for some modules.

Qualitative Research Methods

There is a remarkable parallel between the axioms presented above and the postulates of Mayring (2016), which he understands as methodological principles of qualitative research in distinction to quantitatively oriented research. Qualitative thinking relates to "systemic thinking", because it also assumes complexity, which it does not want to artificially simplify. This clarifies the meaning of the integrative approach once again in concrete terms for the person, the endeavour of the work analyst and work designer, because Maying's postulates also contain direct demands on the acting person. The signals that Mayring referred to as "...qualitative turn ... [as] ... trend towards qualitative methods of cognition..." (Mayring 1986, p. 9) find parallels to Braithwaite et al. (2017, p. viii) for example, who distinguished between "complexity thinking" as opposed to "linear thinking".

In the above-mentioned study programme, qualitative methods are on an equal basis with quantitative methods. Therefore, theoretical basics, methods and instruments are taught. Where complexity cannot be resolved, qualitative methods provide suitable approaches to data collection and evaluation. The module has a high proportion of exercises on the methods and techniques used that are taught in theory and practice, especially considering the integrative approach, the methodology of the Functional Resonance Analysis Method (FRAM, Hollnagel et al. 2014). The FRAM can be attributed to resilience engineering while the methodology is essentially based on qualitative interviews with job holders. The aim is to show actual processes in everyday work and their interconnectedness. The interview results can be transferred into a visual model of the process, for which a special software (FRAM visualizer) is used. Results from ongoing research are incorporated into the lectures as well as experiences regarding the application of the FRAM method (Unger et al. 2022).

The combination of quantitative and qualitative methods and the elaboration of their particular characteristics as well as knowledge regarding advantages and disadvantages offers students a broad selection of methods for analyses and controlled interventions.

Industrial and Organisational Psychology

The module industrial and organisational psychology (e.g. Nerdinger et al. 2019) is deliberately focused on the aspect of "work and technology". The lecturer discusses references and current research as well as recent developments on the subject (e.g. Adolph et al. 2021; Dworschak et al. 2021; Schuh et al. 2021; Mühlbradt 2022). Table 2 displays an overview of the module's topics.

Table 2. Topics of module "Industrial a. Organisational Psychology" Summer Term 2022

Lecture	Topic
1	Introduction
2	Work Systems and Work Tasks
3	Digitalization
4	Human and Artificial Intelligence
5	Effects of Digitalization on Work
6	Work and Requirement Analyses
7	Human-Machine Interfaces and Automation
8	Goal development to Advance Work Design
9	Performance Measures of Mental Work
10	Stress and Risk Assessment
11	Complex socio-technical Systems

Also, topics are taught that cannot be exclusively assigned to the psychological discipline. These topics range from information about other disciplines that shape work, to the basics of automation and machine learning as well as platform economics. Therefore, psychological content must yield sometimes due to limited time resources. In doing so, we follow the view of Rosenstiel (2004, p. 89), that, depending on the specific field of work, non-psychological knowledge can be more relevant than psychological knowledge.

The module industrial and organisational psychology is linked to the module Qualitative Research Methods, as it also provides in-depth information on the FRAM. In terms of methodology, the module focuses on discovery and cooperative learning in small study groups. A script serves as guideline that includes selected original works and case studies. The script is structured into topics with leading questions to each topic formulated for study groups. The lecturer's role is that of a coach after a short presentation of the topic, the materials, and the leading questions. Finally, the study groups present their results and discuss them in the plenary.

Elective Module Independent Research Project
Students can choose between marketing psychology and industrial and organisational psychology in the elective module of the third semester. The following explanations refer to the second option. Students work alone or in teams of two to accomplish an industrial organisational psychology analysis or develop a concept for a company or an institution over the course of the semester. The relatively long time period enables the students to work intensively on a topic and at the same time provides the opportunity to conduct data in the field while the lecturer accompanies and coaches the students during this process. In order to gain practical knowledge as a student it is a good concept to approach participating companies during an ongoing collaborative research project of the university, especially if located in the region. This way, the lecturer ensures that the resulting assignments for the students are demanding, but not overly extensive. Examples of assignments in this module are:

- Risk assessment of mental stress in companies: Consulting and development of appropriate methods, implementation, and evaluation of surveys
- Competence modelling and measurement in companies as well as coaching for employee evaluation and development meetings
- Conception of the unit "Leadership in the digital world of work" within the context of a training concept for companies

Looking at it from a professional perspective, Master's students are able to meet the requirements in the third semester. They also benefit from their life and professional experience within their studies. The coaching of the lecturer therefore includes topics such as "clarifying assignments", "planning work and time" and "how to deal with obstacles". These are important aspects of self-management.

Psychological Competence and Transfer Assessment
Complexity may cause ambiguity, uncertainty, and conflict when linear approaches fail or incompatible views or models of reality clash. It can be important to support people in or at the system to question, change and exchange their models of reality based on the credo "develop instead of design". Skills are therefore taught and trained through case

studies, role plays and exercises in the module Psychological Competence that address these topics:

- Perception and reality
- Active listening and solution-oriented conversational skills
- Dealing with criticism and conflict management
- Crises as starting points
- Coaching

In the Transfer Assessment (TA), students are encouraged to independently compare their level of competence and their competence expectations and thus actively reflect on their competence development. In addition to the kick-off event for the TA as part of the decision-oriented management module in the first semester, events for the presentation of the transfer reports and for transfer reflection take place in the second, third and fourth semesters. Two transfer questionnaires, three transfer reports and a part of the oral examination at the end of the degree programme are required for the examination. The transfer assessment promotes self-reflexivity and runs over four semesters. Expectations of competence development and self-perceived changes with regards to competences are explicitly formulated and documented.

This way, the written and detailed reflection of selected modules facilitates the students own learning and provides an increase of awareness about change processes. These experiences can help to design change processes for other people in the future.

7 Epilogue

In this paper, an attempt has been made to show how the rise of digital work contributes significantly to the dominance of complex socio-technical systems as an essential organisational form of work and value creation. This leads to a crisis of work design, as existing complexity theories and approaches derived from them are ultimately inadequate. In contrast, the integrative model demands the merging of two previously unconnected strands of systems theory so that systemic thinking becomes an integral part of the analysis and design of socio-technical systems. The central idea is that complexity is the same for all actors, cannot be resolved and is ultimately indispensable for achieving the goals of modern work systems. Subsequently, the consequences of this perspective for tasks of and demands on labour analysts and designers were considered.

Healthcare, being considered the laboratory of complexity, Verhagen et al. (2020) indicates that the obstacles in the practical implementation and dissemination of systemic approaches to patient safety that include fundamental changes, do not happen overnight and without problems. In line with this, St.Pierre et al. (2022) still find a too narrow thematic focus on traditional approaches to risk and error management considering the twentieth anniversary of "To Err Is Human".

The legend of the Gordian Knot, which no one can untangle, is well known. Nevertheless, whoever manages it once shall rule. Alexander the Great solved the problem by ignoring the goal of a non-destructive solution to the problem and was thus able to simplify his task considerably: He cut the knot with his sword. The myth of Alexander the

Great is still powerful as a metaphor for resolving complexity. However, the appropriate way to deal with complexity is to recognize it as a borderline experience first. This may well be experienced as a loss of control. However, in the digitalized world of work with unleashed work and high demands on the performance of systems, it will be difficult to find an alternative way in the long run.

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Work-Based Learning in the Mexican Automotive Sector

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Abstract. A stronger work orientation or even the integration of learning into activities will be one of the central basic requirements for the success of Industry 4.0. Using the example of the project E-Mas (Exporting blended vocational education and training for industrial process design and optimization into the Mexican automotive sector), the paper discusses the development and implementation of a highly work oriented further education program. Together the partners Research Institute for Industrial Management at RWTH Aachen University e.V. [FIR], MTM ASSOCIATION e.V. [MTMA], WBA Aachener Werkzeugbau Akademie GmbH [WBA] in cooperation with the Mexican Instituto Tecnológico y de Estudios Superiores de Monterrey [ITESM] pursue the goal of designing and exporting innovative further education programs for skilled workers, developers, and operative management personnel of the Mexican automotive sector and especially German companies operating in Mexico.

Keywords: Further education · Automotive sector · Work orientation · New work · Internationalization · Blended learning

1 Introduction

Under the leadership of the Research Institute for Industrial Management at RWTH Aachen University e.V. [FIR], the MTM ASSOCIATION e.V. [MTMA], the WBA Aachener Werkzeugbau Akademie GmbH [WBA] in cooperation with the Mexican Instituto Tecnológico y de Estudios Superiores de Monterrey [ITESM] have joined for the development of the E-Mas further education program (BMBF, 2017–2021). Together the partners pursue the goal of designing and exporting innovative further education programs for skilled workers, developers, and operative management personnel of the Mexican automotive sector and especially German companies operating in Mexico. For this purpose, a comprehensive, coherent, and certified teaching and learning offer about tactical and operative production management for employees of the Mexican automotive sector was developed and implemented. The training program explicitly considers the current transformation of the companies to Industry 4.0 and thus proactively prevents competence deficits.

The offers focus on the integration and close interlocking of work and learning processes. In this direction, training and education content was further developed and combined into an innovative work-related blended learning-based further education program,

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translated, and offered on-site. Key competencies in the areas of productivity management, work-related learning, toolmaking, and Lean Management are taught to empower employees in the automotive sector in Mexico for the transformation to Industry 4.0 and to promote further industry growth. The training courses are offered in both, the form of a comprehensive overall program and in individual offerings that can also be a supplement to existing teaching content on the customer side. The project acronym E-Mas stands for Exporting blended vocational education and training for industrial process design and optimization into the Mexican automotive sector. It is a variation of the Spanish term '*y más*' [English 'and more'] and expresses the progress and gain in Mexican vehicle and supplier part production through the developed international training program. The transfer and adaptation of the partners' training program are intended to eliminate existing competence deficits given the increased demand for qualified specialist personnel.

The training program developed by the project partners to improve the skills of employees in the Mexican automotive sector consists of four modules:

1) The teaching of new technology-supported and classic concepts of work-related learning in Industry 4.0
2) Competence development in the field of productivity management and industrial engineering
3) Further training in the field of repair and new production of tools for OEMs and suppliers
4) Advanced training in Lean Management methods for Industry 4.0

The subject areas were combined in an overall offer and worked out in extensive modules. Customers will later be able to use the offers of all four requirement areas, or modules in combination, or to decide on case-specific offer packages. A joint marketing concept of the consortium partners was developed and implemented for the distribution of the overall offer. To ensure a flexible offer in terms of time and to quickly achieve economic viability, the training offer was realized as a blended learning concept. Classroom training, an e-learning platform, inverted classroom concepts, webinars [live broadcasts, partly from the Demonstrationsfabrik Aachen, DFA], recorded video seminars and online testing facilities were established. In the DFA, located at the FIR, pre-series vehicles for electric vehicles are manufactured, therefore it is an ideal venue for training in the automotive sector.

The fourth industrial revolution was chosen as the main topic to counteract the shortage of skilled workers in middle management and to enable workers to successfully take over corresponding tasks and activities that fall within this middle management level. The concept focuses on the transformation of companies to Industry 4.0, which could be described as a 'course on tactical and operational production management for the automotive sector in Mexico on the way to Industry 4.0'. In general, production management comprises all activities of planning, ordering, and controlling production in a company. Three different types or levels can be distinguished:

1) Strategic production management: cases of fundamental decisions
2) Tactical production management: implementation of decisions and

3) introduction
4) Operative production management: execution of the daily production management

While strategic tasks are usually performed by academically qualified personnel at management level, tactical and operational tasks are located at an intermediate level of qualification, precisely at the level that the Mexican industry is currently experiencing a high shortage of skilled workers. The aim is to cover the overriding objectives of production management through the E-Mas overall offering and to provide appropriate teaching and learning content. The following four can be identified as these overriding goals:

1) Productivity
2) Employee health
3) The versatility of technical systems
4) Continuous process innovation

The latter two objectives 3 and 4 reflect above all, the requirements for Cyber-Physical Production Systems [CPPS], which represent a paradigm in digital production and are therefore of particular interest for the development towards Industry 4.0. The four partners cooperating in E-Mas can ensure complete coverage of these goals by combining their offers, which is the motivation for this selected consortium to work together in the E-Mas project. The goals are covered by the individual thematic modules of the consortium partners, those modules are dedicated to the fields of, Learning and Working in Industry 4.0 [FIR], Productivity Management and Industrial Engineering [MTMA], Toolmaking Management [WBA] and Lean Management Methods for Industry 4.0 [WBA] (see Sect. 5 for a more detailed description). The offered modules' content is divided into a 5-day course, during which the topic is taught using the multiple resources of the blended learning concept. Considering research being done by the partners of the program, industry cases of challenges, team interaction activities, practical applications with specialized software, and also providing spaces for networking between participants, this serves as a platform to share experiences and solutions to previous challenging situations with a successful outcome. This initial offer can be adapted to the special requirements of the companies, providing a customized solution for each specific case. This is possible due to the flexibility that characterizes the modules and the agility upon which the construction of the entire content offer is based. Figure 1 shows the general consortium structure of the E-Mas Program.

To better introduce this work-related training program, it is not only important to understand the relationship between the Mexican and German economies and their cooperation activities, but also to grasp information about the crucial share that the automotive industry carries in the overall production activities in these markets. Under this context, the content of the courses is developed describing the challenges that the evolution of technology raises and proposing potential solutions that organizations could apply to overcome such challenges. Using cooperation and support projects, companies could enable the development of the appropriate skills in their middle managers for the smooth transformation of their specialized area of work. Chapter two deals with a short explanation of the Customer-Focused Blended Vocational Education and Training Development

Fig. 1. E-Mas program consortium structure [own illustration]

Navigator [CBVET], a tool for the implementation of educational services ideas into the market, under which the E-Mas program is developed. In the third chapter, the E-Mas course principles, its learning taxonomy, and how it is combined with a blended learning approach are clarified, providing insightful information on the general thought structure behind the courses. Furthermore, the content of each course and how it is distributed through the materials of the blended learning concept is analyzed. This serves as the basis for enabling the description of the degree of work orientation for the E-Mas further development training, which is described in the fifth chapter. In the following chapter, the five dimensions and their criteria of evaluation to achieve a high work orientation of the training courses are defined.

1.1 Mexican – German Cooperation Model

In recent years, the cooperation between Germany and Mexico has intensified from an economic perspective as well as from an educational perspective. For instance, Mexico was the first non-European Partner Country at the 2018 Hannover Fair in Germany, one of the biggest industrial technology fairs worldwide. According to the Mexican Ministry of Economy, there are over 1,900 German companies established in Mexico. As these companies are investing a considerably high amount of resources in Mexico, Germany has become the fourth source of foreign direct investment into the country. Thus, leading German companies aim to influence the way other companies operate in the Mexican industry.

Germany has been active in Mexico with some socio-cultural offers in the field of basic education promotion, in which both countries have been working together successfully since the 1970s. Beginning in 1997, the German Society for International Cooperation [GIZ] has been advising the Mexican government on behalf of the German Federal Government (Gesellschaft für Internatinale Zusammenarbeit [GIZ], n.d.). The Mexican government has shown interest in establishing a vocational training system based on the German model in the last years (Dummer 2014). Besides, there are cooperation agreements that are to implement the German-style dual training system, which does not exist in Mexico so far. The German Federal Institute for Vocational Education and Training [BIBB] is working with its partner institute at the Mexican National College of Technical Professional Education [CONALEP] to transfer elements of Germany's dual training system to Mexico (Steinmeyer et al. 2012, p. 29). This is being done within the framework of the project Further development of the Mexican model of dual vocational training [MMFD], a cooperation project of the Federal Ministry for Economic Cooperation and Development [BMZ], the Federal Ministry of Education and Research [BMBF] and the Secretary of Public Education [SEP] in Mexico (Bundesinstitut für Berufsbildung [BIBB] 2017). The project's overarching objective is to introduce dual elements into the Mexican vocational training system, for which the BIBB primarily conducts various advisory activities.

1.2 The Mexican Automotive Sector and Further Education

The automotive sector remains one of the most challenging industries around the world. Consumer requirements are changing rapidly, product lifecycles are getting shorter, OEMs keep increasing their quality and flexibility requests, automation is growing among the part production industry, expansion and internationalization of the product value chain increase, and the use of electric autonomous vehicles is becoming part of a new reality. Mexican automotive companies are appealing to the technologies of Industry 4.0 to meet the market's requirements, and believe that these innovative solutions are the key to improving their productivity and enhancing their production (Mexico Business Publications 2018). However, to transform into a digital factory, business leaders must start by developing a digital strategy that targets organizational aspects [structure, culture, competences], establish the human asset as its main foundation, and settle its leadership as a transformational agent. The growth of the Mexican automotive industry is strongly driven by German companies, which are increasing their international production capacities by expanding existing locations and building new plants (Volk 2016).

In these times of change and when the new normal is conceived under the term VUCA [volatile, uncertain, complex, and ambiguous], organizations are continually experiencing the permanent challenges of the digital era. Political instability, changing needs, intense competition, and the increased control and power of consumers are some of the factors that have urged the automotive supply chain to meet the Industry 4.0 requirements. Most of the companies have been allocating their resources to the development, acquisition, and implementation of new technologies in their production. Nonetheless, they have neglected that one of the most critical challenges is the strengthening and adaptation of current leadership functions and competences. In addition to the technological and organizational modifications, the leadership development approach and the traits, skills, and behaviors that the human talent has, must be adjusted to prepare future leaders for the previously mentioned challenges. In 2015, 1,660 companies operated in the Mexican automotive industry. According to the article 'Crafting the future: A Roadmap for Industry 4.0 in Mexico', 62% of the market players belong to the Small and Medium-sized Enterprises business group (Inegi-Amia 2018). In 2017, the automotive industry produced 20.2% of the Mexican Manufacturing GDP and employed over 824,000 workers, representing more than 1.5% of the economically active population (Inegi-Amia 2018).

In this regard, the Mexican automotive industry, as one of the production leaders in the Western Hemisphere, is expected to grow even more due to the ratification and implementation of the USMCA [United States-Mexico-Canada Agreement].This requires an increase of North-American produced automotive product content from 62.5% to 75% by the year of 2023, and also establishes that 40% of automobile parts are required to be produced in an area where the average labor wage is at least 16 USD/hr., providing the legitimation for Mexican automotive industry to implement better automated processes.

Training and further education in Germany and Mexico, especially in the automotive market, are characterized by differences as well as parallels. Although both countries have compulsory schooling, the general drop-out rate in Mexico is very high despite this (König 2013; Steinmeyer et al. 2012, p. 29). Compared to Germany, Mexican education is generally considered to be overburdened by the requirements of Industry 4.0 and the quantity of students, which, together with the high drop-out rate, implies that the basic skills of many employees cannot be compared with the training standard in Germany. The dual training system, which is considered the figurehead of the German education system, is still being established in Mexico and is thus in its infancy (Bundesinstitut für Berufsbildung [BIBB] 2014). In 2016, about 250,000 pupils were already learning at vocational schools, but without any connection to a training company. The target by 2018 was that a total of 5,000 pupils in Mexico were to be taught in a dual vocational training system (Kramer 2016). Efforts in this area are numerous. However, even the projects implemented to date and those planned to increase the number of skilled workers undergoing dual training are not sufficient to fully cover the current and future demand for skilled workers. As a result, more continuing training measures are needed in addition to initial training. In this way, for instance, unskilled workers can be qualified according to demand and already trained specialists from other areas can be retrained for the automotive sector.

1.3 Demands for the Company Transformation

Digital transformation in all aspects of our life has become the right model when it comes to developing our future environment. As we go digital, we can recognize a series of changes in the production industry that lead us to face new challenges for the development of society, for instance, changing paradigms at the conception and implementation of new ideas. The way consumers perceive products and their core production process is expected to influence their consumption behavior and thus, in turn, influence production methods. Companies with a clear purpose and sustainability mindset increase their chances to thrive positively in the market. But when it comes to production methods, companies are looking forward to being recognized with adjectives such as lean, efficient, low cost, green, high tech and/or innovative. A side effect of the digital transformation is the false argument and belief that jobs for people will be negatively affected. We have already experienced the first, second, and third technological revolutions and these experiences tell us that the transformation only positively changes people's skills requirements. Within the scope of a study, for which200 companies were surveyed, 56% of those expect the number of people in the workforce to stay constant or even increase. Nonetheless, demographic challenges could present special cases, such as in the case of Germany, where the workforce is expected to decrease by 3.5 million fewer trained employees by 2030 compared to today. In this case, it is very likely that digitalization can help to decrease that necessity up to 2 million.

For the digitalization of the industry, a new mindset is required; companies are changing the recruitment processes and the benefits as well to fit new profile demands. New qualifications are already described in job advertisements, and to take the most of what the digital environment has to offer, different strategies are implemented or expected to be implemented in the organizations. Companies expect that highly trained, skilled employees start to grow among their workforce over the next 5 years. In the higher education range, the growth is expected to increase by 5 percentage points, rising from 19% to 24% of the total workforce Vocational training is expected to maintain 59% of the required employment base, and unskilled workers are expected to decrease from 21% to 17% of the total workforce. For instance, the amount of people trained in the areas of data analytics or software programmers is expected to increase, while, on the other hand, the number of line workers required in new production lines will tend to decrease (Geissbauer et al. 2017, pp. 31–38).

A survey was carried out by the Institute of Industrial Management at the RWTH University, to obtain valuable data that supports the development of a leadership framework that satisfies the needs of the Industry 4.0 in the Mexican automotive industry. The survey contained a series of questions that targeted the analysis of People, Technology, and Organization. The results showed that 'Talent development', 'Change-oriented vision', and 'the ability to inspire and motivate collaborators' were ranked number 1, 2, and 3 respectively; respondents also believed that today's and future leaders must have 'Change management', 'Adaptability', and 'Result-oriented vision' within their skillsets (Paez Garza 2020, p. 64).

The concept of leadership development is considered key within a set of skills that define the personality of actors who guide an organization. Moreover, it is critical to note that this skillset evolves along with the emergence of new technology and knowledge. Today, many business leaders are overwhelmed with a wide array of innovative technologies that are saturating the automotive market. As mentioned in the book 'The Technology Fallacy', there is a mismatch between the rate of technological change and the responsiveness that people, organizations, and public institutions have towards it (Kane et al. 2019, p. 29). Leaders are required to develop a business strategy that provides their companies, including all stakeholders, with the capabilities to efficiently embrace the technological, organizational, and social changes that the Industry 4.0 generates.

1.4 Changes in the Corporate Culture

The previously mentioned low availability of professionals capable of performing in digital factories has generated a latent conflict between organizations; this challenge is the result of the other disruptive trends in this branch. Business leaders must strengthen their current human capital development strategy so that they mainly rely on the actual workforce, instead of replacing current employees with external talent. To achieve digital transformation, the adaptation of the corporate culture is one of the first tasks on the 'to-do' list. The organizational performance of a company can be improved when its culture is aligned with the business strategy, its organizational structure, its human capital, and the market requirements. To develop a culture that meets the needs of the digital era, specifically in the automotive industry, leaders must start by determining, which is the current state of their corporate culture, followed by evaluating the industry where the organization operates, considering the maturity of the market, customer requirements, as well as challenges and disruptive trends. To process the evaluation of the actual situation, dimensions or variables must be selected to determine the desired corporate culture. By doing this, executives can locate their organization in a two-dimensional plane that will facilitate the process of identifying the behaviors and core values that their workforce needs to meet with the value proposition of the organization. The alignment of the new corporate culture with the organizational structure and business strategy is the fourth step of the reconfiguration process. High-level leaders are responsible for matching the desired culture with the company's mission, vision, and organizational objectives. By doing this, confusion can be avoided, and cross-functional departments will be able to collaborate in the same direction. The final step is the implementation of strategic measures that allow the distribution of the updated corporate culture; the application of change management methodologies is potentially beneficial.

1.5 Development of Skills in the Workforce

Granting decision-making power, giving regular-basis feedback, and planning career and development paths, are simple but effective exercises that could strengthen the development of talent. Instead of focusing on building the company, managerial staff must practice empowerment and become people-oriented. The upper management cannot grow a company on their own; they need to transform employees into competent leaders, which will then help the company to flourish. The digital transformation requires employees with the mental preparation of driving and implementing change effectively. Strictly related to innovation, head officers must be change-oriented with an adaptable, agile, and malleable mindset that provides them with the ability to detect threats and reconfigure business strategies to maintain competitiveness. Managing change is a 'must' in the leadership 4.0 skillset; promoting change isn't enough, the staff can detect problems and opportunity areas, run diagnostic tools, and implement changes through development, implementation, and improvements.

Motivating others plays a key role in the digital transformation. Encouraging employees to set challenging goals, supplying them with the necessary tools and knowledge to operate efficiently, and leading through others will improve the overall organization's performance. Leaders who empower, ask questions, and delegate authority instead of tasks, will not acquire followers, they will develop more leaders, which provokes organizational sustainability (Craig Groeschel 2018, p. 1). Roy et al. described relationship building as another main skill needed for effective virtual leadership, to build cooperation and trust, there must be a well-defined leader-follower relationship between the work team members. Building a strong and solid relationship can help to solve issues faster and ensure the sharing of information and knowledge between peers. One main component is trust, where all actions count regarding creating an environment of trust at work. Also, delegating activities, honest and non-critical communication, and last but not least, trust is built by fulfilling commitments made to the team (Roy 2012, p. 57). Today product development and production are done through the cooperation between multidisciplinary team members, involved in different stages to solve issues that arise during the life cycle of goods. Therefore, one important skill required by global companies today is the ability to work in teams.

As verbal communication through virtual media becomes of higher relevance, being able to communicate effectively in the work environment is crucial to establish goals at every level of the organization. From the C-Suite to the shop floor operative staff members, transmitting clear objectives avoids waste of time and resources in all processes. In the study of leadership ability to communicate with others, certain personality traits of emerging leaders were given a relatively more important role, which often include sociability, extraversion, nurturance, or assertiveness. These traits are often evaluated directly through the implementation of assessment centers, in which other capacities, such as non-verbal communication, are overlooked. However, this could have its root in the fact that measuring the quality of the message could be a challenging task. As Riggio et al. exposed in 2003, if measuring the impact of a message were easier, it would not be surprising that saying the right words at the right moment would be more important than being extroverted. (Riggio et al. 2003, pp. 83–84). In oral communication, encoding and decoding messages clearly is a critical characteristic for the leader's effectiveness. This is crucial to developing good interpersonal relationships with team members and peers. Encoding provides the correct words by the leader to clearly explain what is required and expected and leaving no doubt in the listeners. Decoding a message includes, apart from listening, also awareness of the time and environment in which the person communicating experiences the events of the message. Another particular characteristic involved in the effective communication is the role-playing of leaders, which is related to self-monitoring. In such situations, leaders analyze their environment and the peers who are sharing the environment to adapt their behavior according to the situation that involves them. (Riggio et al. 2003, p. 85).

Today the digital presence of organizations has become a backbone to attract new customers, improve its public relationships, and even attract new talent to the company. Nonetheless, not all users have developed the same skills and logic to deal with this new approach. Hence, companies must be aware of what skills are necessary to be developed among their employees towards a digital fluency. Initially, Miller and Barlett started with the already described concept of Information Literacy [IL] to describe the ability of knowing, identifying, finding, evaluating, organizing and using existing information to create new knowledge. They also suggested that this term is used as the basis to create the term digital literacy, which is the ability to make an informed judgment about what is found online but making an emphasis on the fact that abilities to reach literacy are independent of digital technology. Therefore, Miller and Barlett suggest that digital fluency includes the abilities that are involved in and related to digital literacy, but have their roots in digital technology. (Miller and Bartlett 2012, pp. 36–38).

Industry 4.0 has forced the organizations to rethink the way they are developing their human talent. Still, many companies rely on traditional classroom-based programs that, for today's changing world, are not adequate. The E-Mas program, with its blended structure, is part of the Vertical and Systemic model that counteracts the deficiencies that traditional horizontal programs have. Some of the benefits that individuals experience by participating in a blended learning course are:

- Participants can immediately apply their acquired knowledge to their own company
- The lessons can be transferred to real-life scenarios, which allows the identification of bottlenecks and problems in processes
- Enables collaboration between participants, both in person and through digital platforms
- Blended-learning programs are self-organizing: the participants can check their progress at any time
  - These programs are responsive, flexible, and tailored.

2 E-Mas Learning Taxonomy and Blended-Learning Concept

The blended learning concept of E-Mas, i. e. the division of training content into classroom- and e-learning content, is based on a comprehensive learning taxonomy that was used for each learning unit and allows a division according to didactic and pedagogical aspects. In general, a so-called inverted-classroom concept was pursued. This means that factual knowledge and basic conceptual knowledge are first conveyed using e-learning before more in-depth conceptual and procedural knowledge is taught in the form of face-to-face sessions. This was followed by training tasks, both in the form of e-learning units and live broadcasts. Furthermore, digital examination formats were tested and implemented, and digital success control was carried out regarding the concrete application of the learned content and the implementation of the participants' learning objectives. The overall pedagogical and didactic design paradigm of the planned inverted-classroom concept was adapted to the technical, cultural, and economic conditions and, above all, to the requirements of the respective customer. In the following, the E-Mas concept for defining e-learning content is described in detail.

The concept of so-called blended learning refers to teaching and learning arrangements that combine e-learning and face-to-face learning (de Witt & Czerwionka). A further distinction is made between face-to-face learning with the accompanying use of digital media, (de Witt & Czerwionka) synchronous [e.g. webinar, social media], and asynchronous e-learning (de Witt & Czerwionka; e-teaching.org). In addition to the advantages of blended learning [e.g. more self-determined learning, application orientation and flexible design of teaching-learning scenarios, reduction of financial expenditure, better availability of learning materials] in teaching and learning arrangements (Acatech 2016; Gundermann 2015; Bundesministerium für Arbeit und Soziales [BMAS] 2016b; e-teaching.org 2017), the use of media has the additional benefit of promoting media competence [digital literacy] working world that is becoming more digitalized (Bundesministerium für Arbeit und Soziales [BMAS] 2016a; CEDEFOP 2015).

In principle, E-Mas is based on the concept of learning solutions (Gundermann 2015; Eichler et al. 2013; Kerres 2012; Seufert and Schuchmann 2013). These are understood as innovative learning solutions that draw on current pedagogical, psychological [including cultural aspects], didactic, methodological, and technological findings. This includes the user-oriented combination of new technologies, learning formats and processes, learning environments, and business models, and the consortium aimed to realize the best possible combination of learning arrangements in E-Mas, against the background of the pedagogical, technical, cultural, and economic requirements and conditions.

3 Approach for the Development of E-Mas

The approach of the Customer-Focused Blended Vocational Education and Training Development Navigator, in short CBVET-Development-Navigator, reflects the development approach, which was applied in developing the E-Mas further education program. This CBVET-Development-Navigator accompanies the process from an idea of educational services to its implementation in the target market, to maintain the competitiveness of the company and to master the barriers of internationalization of further education. The Navigator's customer orientation is characterized by the specific survey of the individual training needs of the customers, which are trendsetting for the conception of a training offer. This tool contains iterative feedback loops, especially in the conception phase, which enables the customer to give feedback on the current educational concept. Furthermore, it provides an approach to implementing a high-quality, profitable educational service. Besides, the CBVET Development Navigator serves as a planning tool for the development of educational services as well. It is characterized by its iterative and agile character: Although the three phases of the Navigator – analysis, conception, and implementation – have a clearly structured and deliberately chosen process sequence, they can be repeated as often as required. Figure 2 gives an overview of the CBVET-Development-Navigator.

Each of the three phases, analysis, conception, and implementation, consist of three iteration stages. With each higher iteration level, the steps of the respective phase become more concrete. This means that the individual steps become more specific and detailed as the process progresses. Within the iteration stages, no sequential procedure is provided. To achieve the phase-specific goals within these steps, selected methods are proposed. With the help of the respective method, the steps can be fulfilled in the best possible way. It is important that the methods also differ in their complexity and degree of detail. In lower iterations, the respective method takes up fewer resources and time than in higher iterations. The step e-learning takes on a separate role concerning the further steps. E-learning is covered in each of the three phases. In the first phase, e-learning is analyzed,

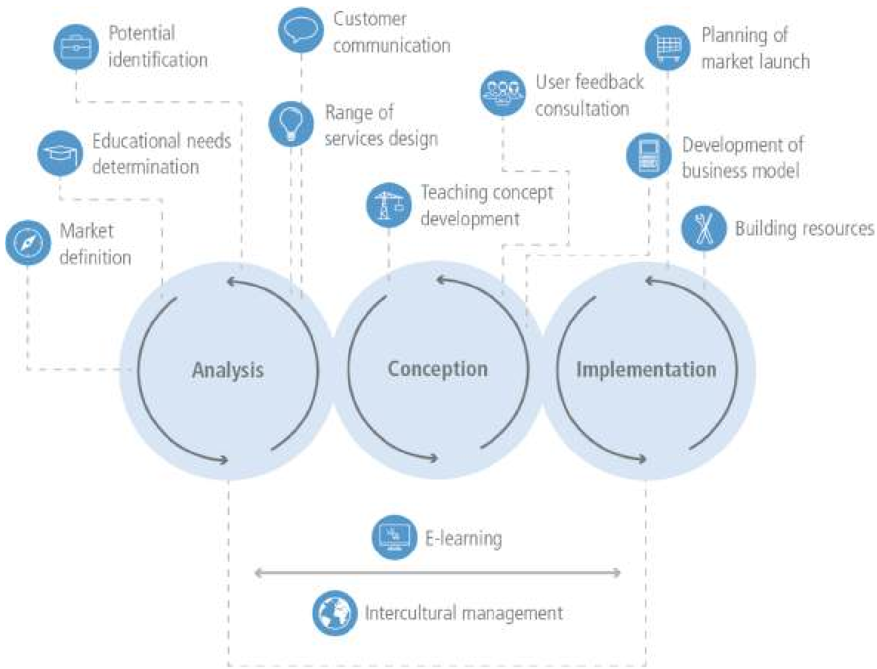

Fig. 2. Overview of the CBVET-development-navigator [own illustration]

defined in the conception phase, and finally implemented. Another special feature is the culture analysis, which is synchronized with all phases.

4 Work-Related Training Design

In most cases, a lasting competitive advantage is based on the knowledge available in a company. Even if markets change, new competitors enter the market or services and products reach the end of their life cycle, successful companies know how to defend their position because they can constantly generate new knowledge, make it available in a targeted manner within the organization and quickly transfer it into innovative services and products. A stronger work orientation or even the integration of learning into activities will be one of the central basic requirements for the success of Industry 4.0. In this context, previous qualification measures should be examined to see to what extent they meet the requirements of Industry 4.0 and how existing concepts can be made more work-oriented. In principle, 'learning at work' and 'learning far from work' can be distinguished as opposite poles. However, this does not mean a simple dichotomy. Rather, personnel development and qualification measures can exhibit numerous different degrees of 'work orientation', i. e. a pronounced proximity to the pole 'learning at work'. This work orientation can be further differentiated into 8 sub-dimensions, which reflect the classical elements of methodology and didactics from pedagogy. Highly work-oriented learning can therefore be described as 'learning close to work'. Figure 3 shows the model in overview.

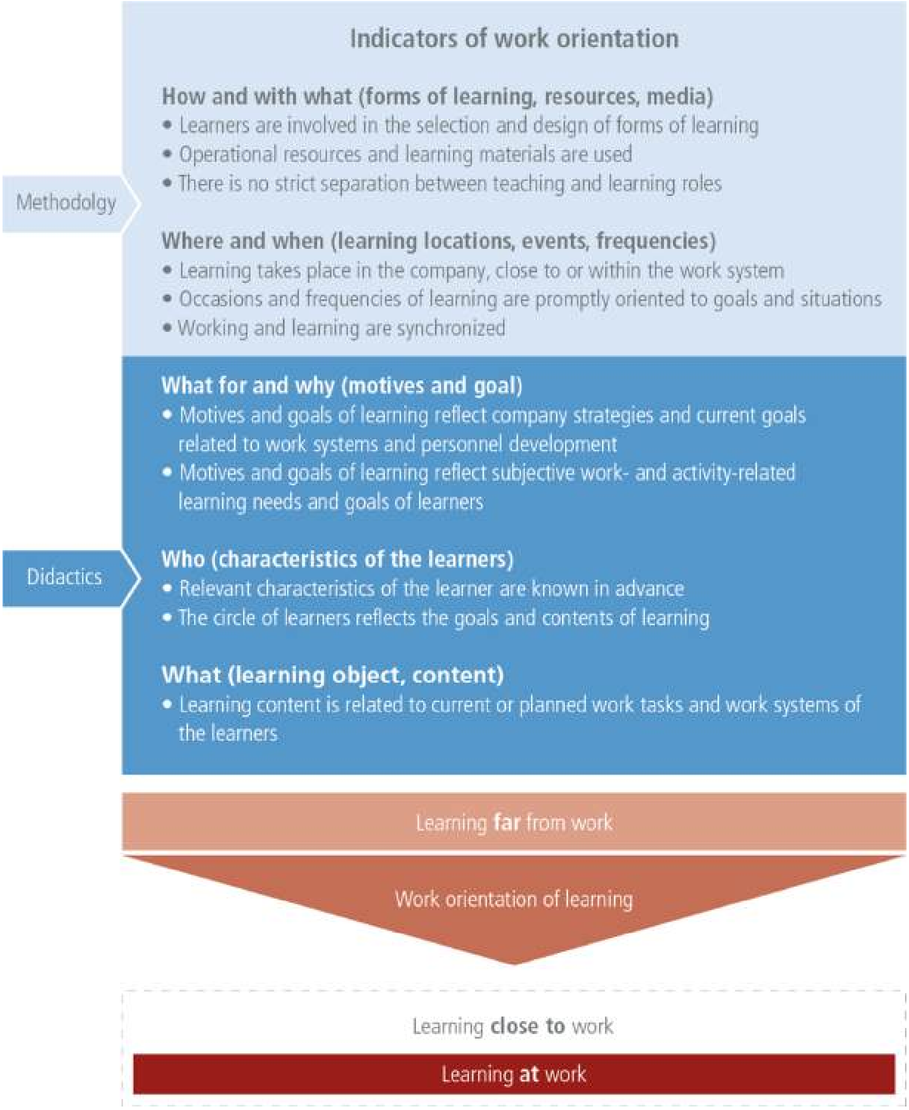

Fig. 3. Learning at work model (own illustration based on Mühlbradt et al. 2015)

First, it should be noted that the comments apply both to ‘implicit’ learning in the process of work and ‘explicit’ measures of personnel development and qualification in companies. As a side effect of work, implicit learning always takes place unsolicited. However, it cannot be assumed that learning at work always takes place to the necessary and desirable extent just because work is being done. If one understands the concept of learning facilitation as the sum of the conditions, ‘…which favor learning processes or create conditions favorable to learning when carrying out work in everyday working life’ (Bigalk 2006, p. 38), then these conditions also include at least questions of task design, management behavior, and access to relevant data and information from the work system. These further aspects are not dealt with here.

Digital learning as IT- and data-supported learning is increasingly coming into focus (Lutz Goertz 2014). The potentials of information and telecommunication technology, e. g. the internet, social media, tablet PCs, smartphones, data glasses, do indeed offer technical foundations for a wide range of learning forms and learning settings. However, it is rightly pointed out that this potential must be converted into functional and needs-based 'Learning Solutions' (Eichler et al. 2013, p. 6), the focus of which is not the technology but the benefit for the learner. Digital systems therefore only play an indirect role in the present context by helping to implement work-oriented learning solutions and to achieve desirable levels of certain indicators. Due to increasing customer requirements and more complex contractual terms and conditions, companies are faced with the challenge of constantly having to adapt and further develop the competences and skills of the responsible location managers and project managers in the area of order management. For this purpose, the existing qualification measures in the area of order management can be examined with the help of the analysis tool developed by FIR and MTM.

The following five dimensions were defined for the analysis tool: Learning content & learning objectives, organization, methodology & didactics, transfer, and sustainability. For each of these dimensions, different parameters were defined, which allow an evaluation of the degree of work orientation of qualification measures. In this context, various degrees of differentiation between the extreme points of a purely seminar-based qualification and a work-integrated qualification are possible. Figure 4 provides an overview of the analysis grid used.

Within the first dimension, it is necessary to question whether learning content and learning objectives are also geared to the actual needs of the respective company and whether these are also continuously surveyed. Also, content can be very abstract and general, or it can be tailored to the specific issues in the company.

The second dimension deals with organizational issues. For instance, a seminar-based qualification, the training courses of which are typically organized centrally by the company and the employees can hardly influence the selection process. Furthermore, neither clear personnel development goals are formulated, nor career planning takes place. The involvement of company experts such as those involved in the planning of work systems can obviously have an enormous impact on the extent to which learning processes can be integrated into the actual work. A further decisive point for the work orientation of qualification measures also manifests itself in the selection of instructors, because while internal instructors can refer to company-specific challenges, external instructors will tend to convey generic content. Finally, in the organizational dimension, it must be decided how the qualification measures are organized in terms of time and location. For instance, employees can be seconded for longer external training sessions, or the training content can be taught on-site as required in the work process.

The methodology & didactics dimension covers the design of the forms of learning in which the content is prepared. For instance, a seminar-based qualification is typically based on a textbook, while a work-integrated qualification is more likely to be based on case studies. The same applies to the design of tasks to be solved, as this can take

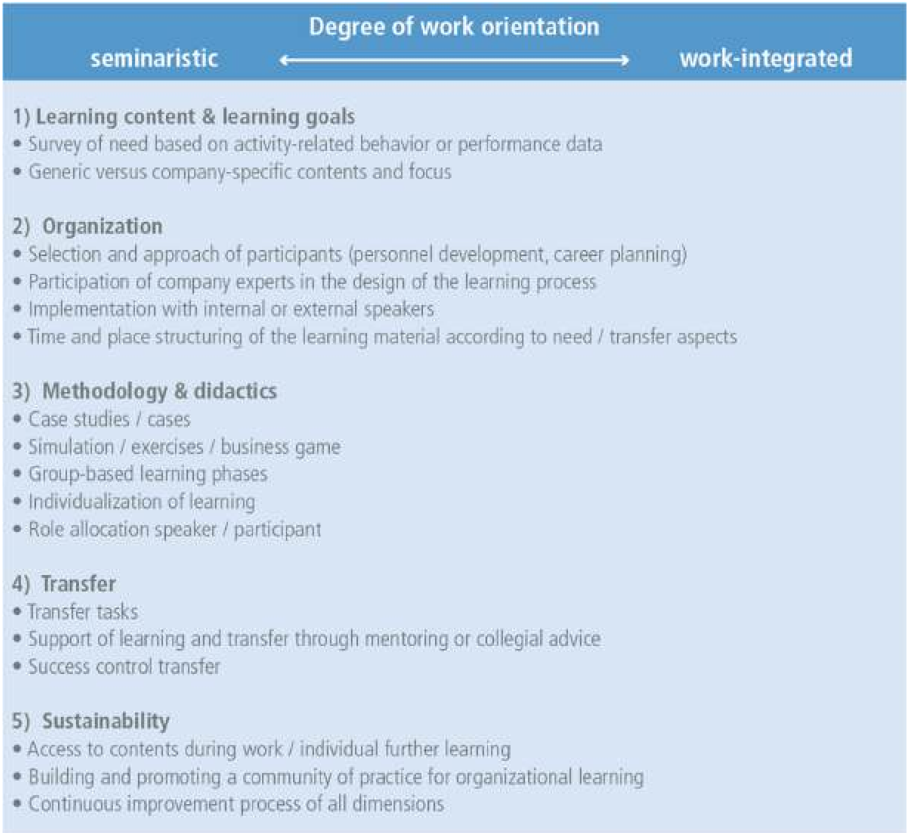

Fig. 4. Analysis tool to evaluate the work orientation of training (own illustration based on Senderek et al. 2014)

place in the form of classical exercises or be supported by business games and simulations. A further characteristic feature of a work-oriented methodology & didactics is group-oriented learning phases which, in contrast to classical frontal teaching, require the active participation of the participants. Furthermore, it is conceivable that learning content can also be tailored to the individual needs and abilities of the participants within corresponding learning groups. Finally, in the case of work-oriented qualification measures, the distribution of roles between instructor and participants can also be resolved, i.e. the participants themselves give lectures on their special fields and prepare parts of the lessons independently. Accordingly, the head of the training moves into the role of a moderator. The fourth dimension describes the transfer of imparted knowledge into practice. In this way, concrete transfer tasks can be directly linked to the qualification measure to achieve a stronger work orientation. Mentoring programs that go beyond the actual qualification measure can also support the transfer of what has been learned into practice.

The last but also central point of the dimension transfer is the control of success. Only continuous success control can ensure that what has been learned finds its way into practice or that obstacles are identified that need to be removed. The last dimension closely linked to transfer is the sustainability of qualification measures. Thus, a higher work orientation can be achieved if the content can be accessed during work and individual further learning is supported by additional content. Sustainability can also be significantly supported by building up a community of practice and thus individual learning processes can be combined into organizational learning. Finally, for the sustainability of qualification measures, it is important to ensure through continuous improvement that all the dimensions mentioned above are further developed and, if possible, are increasingly oriented towards work (Senderek et al. 2017).

5 Work Orientation of the E-Mas Program

To achieve a high work orientation, the E-Mas partners applied the analysis tool mentioned in the previous paragraph. Each of the four courses was designed along the five dimensions and evaluated along with the determined criteria. Thus, in the following the four E-Mas courses will be reflected accordingly. Generally, high applicability was intended for the Mexican automotive sector to ensure learning content preparing the participants for real practical work situations.

5.1 FIR Course 'Chief Workplace-Innovation Manager'

The certificate course 'Chief Workplace-Innovation Manager' of the Institute for Industrial Management at RWTH Aachen University provides participants with extensive expertise in the fields of competence development for the transformation towards Industry 4.0. Important topics that will be dealt with include the goals of transformation, the creation of working environments that promote learning, the integration of competence development and work processes as well as comparative management approaches for dealing with German and Mexican cultural differences. The target group consists of specialists and operative executives in the fields of work design, production management, and human resources management.

During the development of the course, intensive surveys in the form of personal interviews and questionnaires have been conducted to identify special needs. Furthermore, the content is less generic and far more highly company-specific, especially regarding company development. Thus, even a module about intercultural management was developed since this is an important challenge in German companies. Learning methods in the module 'Work design and competence development that promotes learning' were selected according to the specific needs of the Mexican automotive sector.

The participants were selected by companies and their respective HR/production departments and at the beginning of the course, a competence balancing by e-learning was carried out. Participants were motivated to use their company examples and to present real-life problems to develop real practical solutions. Moreover, courses were mostly planned as in-house courses.

The principles of the methodology and didactics of the course are reflected in case-based learning units. Apart from this, great importance is attached to the fact that face-to-face course units and e-learning units took place as group learning phases and group work. However, each participant, whether in group or single work, learned how to compile and learn for themselves during individual tasks.

Transfer tasks had to be defined at the end of the course to all three modules and were checked 3–6 months later. Also, supervisors were informed about the content acquired in the course to foster implementation and promote positive developments in their teams.

Before the implementation and during the execution of the course, the e-learning units were professionally accompanied. Most importantly, constant access to the learning materials was made possible through the e-learning platform. Furthermore, to ensure the flexibility and agility of the learning content, continuous adaptions and improvements to the course were made by including feedback and further developments of the content.

5.2 MTMA Course 'MTM-Practitioner'

The MTM ASSOCIATION offers courses to achieve the MTM-practitioner qualification. The MTM practitioner is the guarantor for MTM's compliance, accordingly, being the contact person for works councils, employees, and executives to design the MTM application in the company. Qualification as an MTM practitioner conveys knowledge and skills for the application of the MTM process, in particular the application of the individual MTM process module systems for the planning, design, and optimization of processes, work systems, and products. The target group consists of specialist and operational executives from the fields of industrial engineering, planning, time management, work preparation, production, logistics, occupational safety and health, product, and equipment construction as well as the works council and other interest groups.

Here too, intensive surveys were conducted. For this purpose, personal interviews and questionnaires were carried out to identify specific requirements. Special focus was laid on the training of the MTM experts in Mexico and the cooperation with MTM Mexico was important in this respect.

The participants for the course were selected by companies and their respective HR/production departments and the courses were mostly planned as inhouse courses or completely planned as e-learning courses. As real-life examples and problems in work situations are highly educational, participants were motivated to use and share their company examples.

The course is based on case-based learning units to ensure work orientation. Moreover, group learning phases and group work promote individual learning potential.

The support of learning and transfer through refreshment training after three years for MTM instructors has been proven to be successful. Furthermore, supervisors were informed about the content acquired in the course to foster implementation.

Printed MTMA learning material was handed over to each participant and constant adaptations to the course involving feedback were made.

5.3 WBA Course ‘Expert Industrial Tool and Die Making’

The certificate course ‘Expert Industrial Tool and Die Making‘ of the WBA Aachener Werkzeugbau Akademie, contains core elements of industrial tool making and conveys to the participants’ concrete concepts and methods, with which traditionally more skilled tool-making companies can develop into industrial tool-making companies of international standard. Upon completion of the course, participants will be able to use current manufacturing technologies to optimize tooling processes, detect tool damage, and self-remediate. The target group consists of manufacturing professionals and operational leaders in toolmaking at Mexican automobile manufacturers and suppliers.

Before developing learning content, intensive surveys were conducted – personally and with questionnaires to identify special needs of the company. Moreover, the learning content was aimed at highly company-specific development, thus, even different formats were implemented to customers’ needs. For instance, a one-week course and a three-week course were established and a stronger focus on repair and maintenance was offered.

Once more, the participants were selected by companies and their respective HR/ production departments, and participants were motivated to introduce their company examples and present real-life problems they faced in everyday working situations. The courses were mostly planned as in-house courses or in facilities that enabled learning with machines and tools.

The structure of the course was based on case-based learning units. Furthermore, great importance was attached to face-to-face presence course units, and e-learning units took place as group learning phases and group work. However, individual tasks were not neglected, so that optimal learning results, whether in a group or single work assignments, were ensured.

The support of learning and transfer was made possible by performance reviews. On that, supervisors were informed about the content acquired in the course to foster implementation.

The sustainability of the content was ensured by accompanying webinars before the beginning and during the course. Adaptations to the course were included after obtaining feedback from the participants and companies. Moreover, permanent access was provided by media [tablets] during the course.

5.4 WBA Course ‘Lean Management 4.0 Production Expert’

The certificate course ‘Lean Management 4.0 Expert’ of the WBA Aachener Werkzeugbau Akademie, imparts the participant’s application-oriented knowledge and ability regarding the introduction and implementation of principles and methods of Lean Thinking for Industry 4.0. Lean Thinking is based on the five basic principles customer value, value stream, flow processes, pull principles, and perfection. In the course offered by the WBA, these principles are picked up and extended by the perspective of transformation according to a future-oriented and sustainable lean training. The target group consists of specialist and operational executives entrusted with the implementation of organizational change processes in the areas of production, administration, maintenance, and development.

To develop learning content and goals, intensive surveys were conducted. This took place in the form of personal interviews and a questionnaire to identify special needs. Lean experts of TEC de Monterrey/ITESM participated in the tailor-made course development.

The participants were selected by companies and their respective HR/production departments and in the beginning, the courses were mostly planned as in-house courses. Participants were encouraged and motivated to use their company examples and to present real-life problems to develop real practical solutions.

The methodology and didactics are characterized by interactive workshops, group learning phases, and group work and, to ensure a well-rounded learning result, an individual task that requested the application of the already learned content.

The participant's supervisors were informed about the content acquired and used the results of the success controls in the course to foster the implementation of the knowledge attained.

To ensure the flexibility and agility of the learning content, constant adaptions, and improvements to the course were made by including feedback into enhancements of the content. The focus from an all-over Lean perspective was adapted during the project to a stronger focus on Lean production.

6 Conclusion

In general, the work orientation of the E-Mas program has proven to be one of the key success factors for entering the Mexican automotive sector. Especially it was important to adapt the courses to the customers' topics and to integrate real-life cases into tasks and group works. The blended-learning concept supported the work orientation of the E-Mas courses since more general and basic content was taught by web-based-trainings, whereas webinars were used for content that requires more feedback. The training sessions, which required an even higher degree of interaction, were taught in presence. This also holds for training programs especially in the area of tool and die making in which machinery was required to perform training sessions on-site.

In addition, it became obvious that a constant and agile adaptation of content and methods was able to raise the satisfaction of the E-Mas programs' clients. The courses needed to be adapted to the requirements of the different clients and the mixture between web-based-training, webinars and presence learning had to be determined in cooperation with the respective client.

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Capacity Building for Digital Work – A Case from Sino-German Cooperation

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Abstract. The way humans work is constantly changing. This has always been the case, especially in dynamic environments. In the context of Industry 4.0 and the Internet of Things (IoT), collaborative platforms, accelerated by Artificial Intelligence (AI) technologies, give rise to new automation opportunities of complex and previously labor-intensive tasks, while also creating new business models for multiple stakeholders.

Due to accelerated product innovation, the manufacturing industry needs to be able to generate solutions in a timely manner and quickly move them into production according to customer expectations. Today, machines in an Industry 4.0 factory are collaboratively connected. Such a development requires the application of advanced predictive tools that can systematically transform requirements and data into information and ultimately knowledge to manage uncertainties and make informed ad hoc decisions. In this context, a production system needs to perform rapid self-reconfiguration in response to different product characteristics to achieve an agile transition to the new manufacturing processes. However, a large number of non-standardized device interfaces and communication protocols are currently existing on the shop floor, which leads to high time and capital costs. Furthermore, this leads to insufficient reliability in the configuration of the production system, so that the requirements for customization and rapid adaptation cannot be met. In addition, there is also a large knowledge gap in the academic field of self-configurable intelligent production systems using collaborative engineering and IoT platforms.

Therefore, Karlsruhe Institute of Technology (KIT, Germany) and Tongji University (Shanghai, People´s Republic of China) have proposed the collaborative "Construction, Reference Implementation and Verification Platform of Reconfigurable Intelligent Production Systems" and the "Factory Automation Platform", which meets the challenges of self-configuration, agile response, accumulation of domain knowledge and services, intelligent operation and maintenance of production systems.

Keywords: Factory automation · Industrial internet of things · Capacity building

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1 Introduction and Motivation

1.1 Motivation and Goals

Due to the continuous emergence of new products and the acceleration of product complexity, enterprises are required to quickly obtain production system solutions and to smoothly put them into production according to market demands. At the same time, production systems have to be able to change with the product design through rapid reconstruction and generate the corresponding technical scheme of intelligent features [3, 6]. Currently, there are a large number of non-standard equipment software interfaces and communication protocols, resulting in long build times and low reliability of production systems, which significantly delays the market entry of new products. Established companies, especially those that integrate and operate production systems, often know the characteristics of Industry 4.0 and are therefore able to identify or define the relevant features of the systems and products, but new companies usually lack this knowledge and capability. Therefore, the market for reconfigurable intelligent manufacturing system features, or in other words, the demand for "turnkey production systems" is growing rapidly, compared with traditional manufacturing [9]. A common marketplace for manufacturers, system integrators, service providers, agile and rapidly evolving requirements, especially considering configuration, reconfiguration and monitoring of production systems as a combination of integrated services, is a viable and efficient way for all stakeholders in the process of creating production systems [1].

Manufacturing companies are facing big changes in the current industrial environment - the dynamic market demands, increase in personalization, pursuit of high-quality products, flexible production batches, shorter product life cycle, and so on, which force manufacturing companies to realize high flexibility, driving the transition of the traditional production system to the next generation of manufacturing systems [4, 5]. The flexible production model oriented to Industry 4.0 can respond quickly in the continuously changing market, shorten the period from the establishment of product development and production system to the commissioning, and flexibly schedule the system operation process to improve production efficiency (especially on the shopfloor). The realization of flexible production is inseparable from the fast matching, connecting, debugging, and operating of functional components in the production system. So, Plug and Play (PnP) is one of the key features of future manufacturing. To realize PnP equipment and software, it is necessary to integrate and encapsulate all kinds of hardware and software in standard modules and connect them with unified interfaces and data formats [2]. In addition, real-time, efficient, and stable communication means are needed to guarantee the rapid operation and interaction of the equipment, especially for the reconfigurable PnP modular equipment, which sets a higher demand on the strong compatibility and rapid configuration of communication.

1.2 Research Goal

The purpose of a turnkey engineering platform is to quickly obtain production system solutions according to product design requirements. Production systems need to be reconfigurable and to include certain smart elements or "intelligence". At present, there are many non-standard equipment and communication protocols, the planning and construction process of a production system takes a long time, is highly cost intensive with often poor reliability, resulting in serious delays in the overall production process. The aim of the project was to study the reconfigurable intelligent architectures and digital twin models of production systems, to build a reconfigurable intelligent manufacturing system for an Industry 4.0 platform. Through the research and development of enabling technologies such as system configuration and model drive, the project quickly generated a turnkey engineering production system solution, and simulated and evaluated its business model and trial operation status by reorganizing the production system of the platform.

The main goal of the project is to build a software-supported and model-driven factory automation platform through a use case driven construction of a connected reconfigurable intelligent production system. The key scientific problems to be addressed are threefold:

1. Development of a reference architecture and instantiation enabling tools for turnkey reconfigurable intelligent production systems;
2. The construction of digital twins for reconfigurable intelligent production systems heterogeneous integration and reconfiguration methods;
3. Implementation, validation and demonstration of the digital twin-based reconfigurable intelligent production system.

The key contribution here, is the development of methods for configuring the turnkey production system, the definition of interfaces, the development of the configuration logic, the creation of the digital module models and the conception of embedded systems to make components smart, i.e. network-capable. Furthermore, methods for the continuous simulation of turnkey production systems are developed. This can also include procedures and the adaptation of simulation methods to simulate the value streams through the plant. In addition, control modules (for operation on the hardware level) and for controlling the overall system (e.g. material flow control, Manufacturing Execution System (MES) etc.) are to be integrated. Thus the factory automation platform has the potential to reshape how work tangent or related to the integrated production planning process, e.g. product development, consulting services, production planning, integration, procurement, plug & play, build, quality management, production monitoring as well as other accompanying services are being executed.

1.3 Structure

In the Industry 4.0 factory automation platform, participating companies are not only involved as suppliers of materials and users of the platform, but also establish themselves as system integrators on the platform and take on coordinating tasks in the medium term. Chinese industrial companies, in particular as suppliers of subsystems for turnkey production systems, but also German companies are to be integrated via the platform. The framework of this integrated Industry 4.0 factory automation platform offers the opportunity to address further research questions, in particular regarding open, modular German-Chinese research. For example, questions from the field of logistics, production processes, digital process chain or network architectures. It also enables the expansion of this platform to include other research centers and research partners as required.

The architecture of the reconfigurable intelligent production system is shown in Fig. 1. Key technologies include the Industrial Internet of Things, common interfaces and standards for machine tools, configuration of communications, and digital twin models. Specifically, the research objectives of the physical layer and cyber layer of the project include the following:

Physical layer

- According to the requirements of the turnkey production system, the granularity, interfaces and modular attributes of functional units of reconfigurable intelligent production systems have to be defined for its whole life cycle.
- Through the unit configuration function, the reconfigurable production system reference architecture for personalized customization is build.
- On this basis, an enabling tool for system construction, reconstruction and quick verification is developed.

Cyber layer

- Establish the digital twin model of the modular units of the intelligent production system, define the communication logic of the digital twin models of each functional module, establish the system configuration method;
- Determine the configuration logic of physical systems and digital twin models to validate the configuration process; Establish the digital twin model of the intelligent production system driven by real-time data of the physical system.

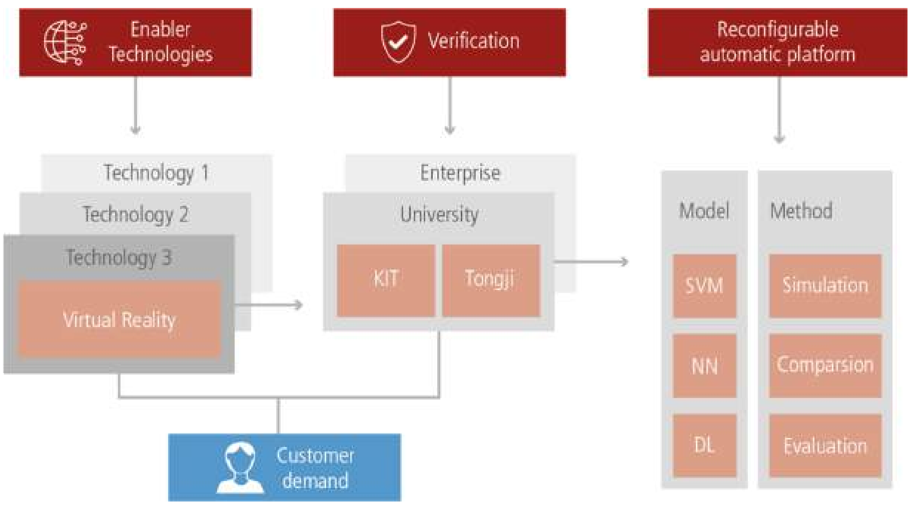

Fig. 1. Project architecture (own illustration)

2 Digital Enablers

The following chapter presents a selection of methods and digital enablers primarily integrated in the digital process chain for configuring adequate production systems.

2.1 Agile Development

Using agile development techniques, the project team created a mock-up of the platform to communicate its value proposition and possible application scenarios. Using a web-based interface the mock-up was then transferred into a minimum viable product (MVP) through which user studies could be done and single applications and services could be integrated and tested early on.

2.2 Digital Module Models

To plan entire production systems and automatically configure them according to particular product designs, the computer internal representation of the individual elements, which compose the production systems, has to be modeled in a way that enables attribution of components, tools, machines, as well as production systems as well as their categorical dependencies and interfaces to procedural requirements. Furthermore, procedural requirements should also be automatically derived from material composition, geometry, product manufacturing information. When optimizing for cost and efficiency, the ultimate processing recommendations are influenced by the set of information about already existing tools and machinery. Therefore, a digital module model description was generated mostly derived from current digital twin description models in accordance with RAMI 4.0 and the asset administration shell to represent assets and their relationships with each other in a common (model based) systems engineering approach.

2.3 Feature Recognition/Process Identification

Using known techniques from CAD-CAM tools, product geometries in the standard exchange format STEP, including product manufacturing information (PMI) were used as product description. We use algorithms to analyze the geometries, to extract features that can then be translated into potential processing steps.

2.4 Machine Tool Selection

Having detected and selected potential processing steps for the production of the product to be build, now machines and tools have to be selected corresponding to the individual processing steps. This is multidimensional optimization problem where time, costs, maximum number of pieces for manufacturing, energy consumption, raw materials, design adjustment feedback loops, etc. have to be taken into consideration. We therefore considered only three possible optimization criteria, that mostly can be translated into a function of costs and time, resulting in a limited amount of potential machine configurations to be validated.

2.5 Layout Generation, Validation and Optimization

After generating the production system configuration, we combine processing information, processing order, machining attribution, machine geometries (CAD-Data) together with the workshop floor plan to automatically create visual layout propositions, 3D-process simulations of the production processes as well as logistics processes to enable a fast and interactive production system planning as well as a validation process via the platform. Figures 2, 3 and 4 show the different development stages of this process including various use cases. In Fig. 2 we can see a layout proposition for a production system. Using a general representation for material source and sink. The red line represents Space around the modular units required for maintenance and other work on the machine. The blue turquoise line represents the material flows and can be adjusted. All machines can present key performance indicators and are flexibly adjustable in their positioning and orientation.

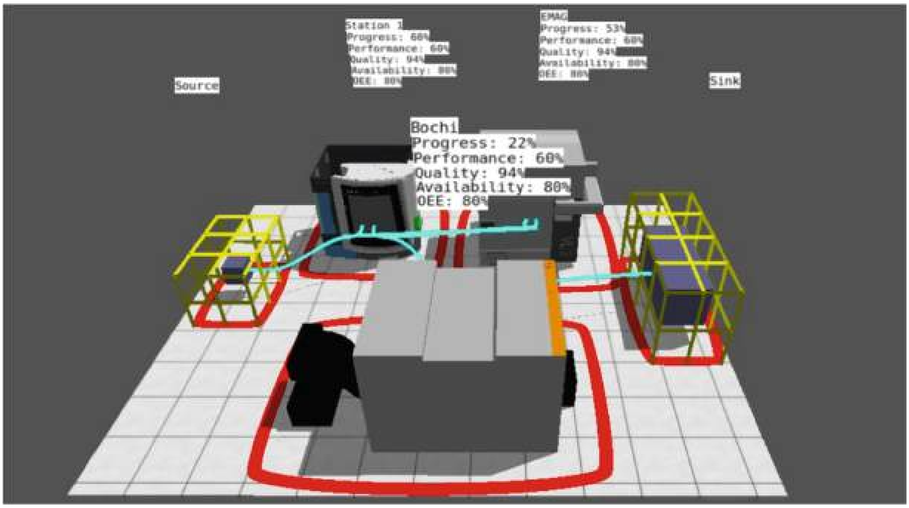

Fig. 2. Automated layout generation (own illustration)

In Fig. 3 we use a modular layout of production components of fixed sized modules and production components, where small production elements stand atop of modular table sized units. The handling of work pieces is performed here by a robot unit (UR5). Whereas the green outlined boxes represent buffering stations.

Figure 4 shows an integrated view of the web-site mock-up where a potential customer can visualize his or her production system configuration and adjust it interactively. After the setup of the production system, the platform can then be used for live updates and monitoring purposes.

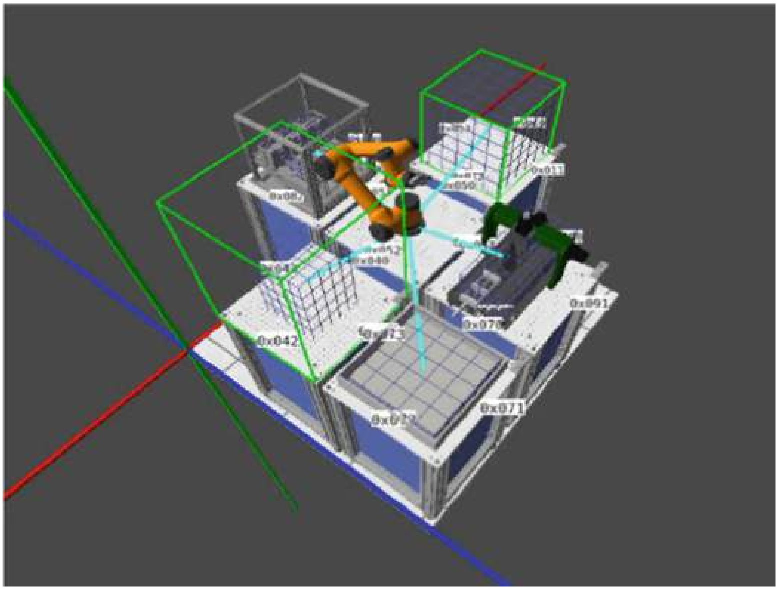

Fig. 3. Production system configuration simulation of a process workflow on a web-based platform prototype (own illustration)

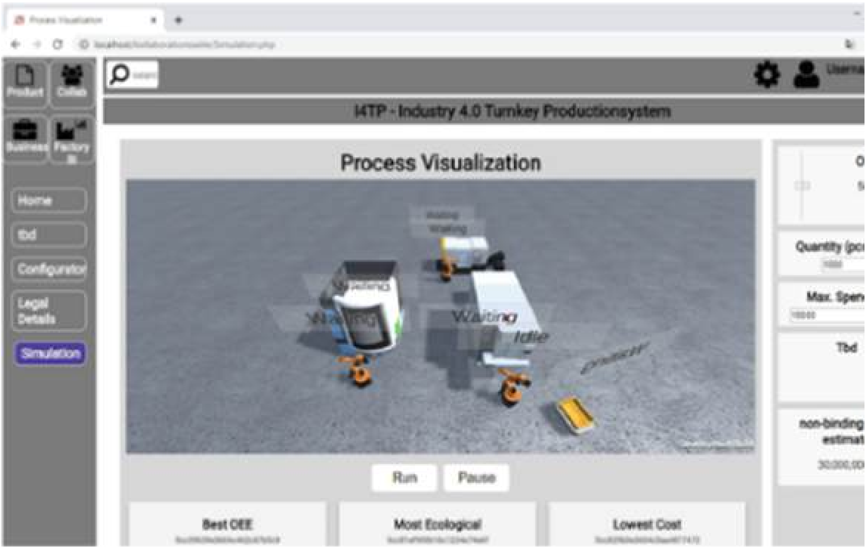

Fig. 4. Automated layout generation on a modular demonstrator (own illustration)

3 Application Scenarios

3.1 Plug-and-Play Application - Communication Technology for Digital Twins

The 5G technology enables high growth potentials in the manufacturing sector [7], providing readily available rich data for processing machine information, sensor feedback and twinning capabilities for big volumes of data. When trying to achieve a quick set-up or the reconfiguration of a turnkey ready production system of functional units, the further development of the Industrial Internet of Things (IIoT) and Cyber-Physical Systems (CPS) are part of the main issues that need to be resolved [8]. Promoting and advancing the development potential of future manufacturing industries will therefore be enabled by the use of 5G technology to realize the agile real-time transmission of large amounts of data, combined with a standardized modular design to achieve plug-and-play capability of functional units and the use of IIOT and CPS. In order to create application scenarios for the quick setup and operation of production systems, the Advanced Manufacturing Technology Center (AMTC) at Tongji University (Shanghai, China) carried out a self-optimizing factory design and implementation of 5G-based turnkey applications. Additionally, at the AMTC, use cases were created for research and enhanced students' awareness of 5G and plug and play in the industrial sector.

For demonstration purposes, a single standard modular unit and a collection of modular sub-units were developed on the basis of modularized digital twin components. Here, the German and the Chinese partners used different but similar modular technical components (the Chinese partners used iSESOL-modules whereas the German partners utilized a similar demonstration line at KIT with functionally similar component and modules). The standard module unit demonstrates the design of the Plug and Play

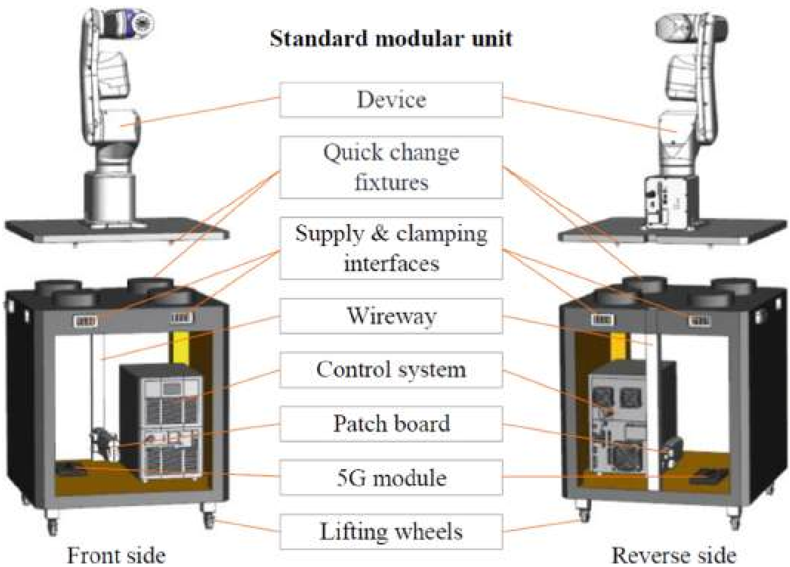

Fig. 5. Structure of the standard modular unit [10]

module. The collection of modular components, which are potentially not standardized, provides users the chance to test out small-scale 5G-based turnkey production system applications, where manufacturing- as well as assembly steps are being integrated into the processes.

Figure 5 depicts the structural makeup of the Chinese standard modular units. The module integrates lifting wheels, a 5G module, control systems, supply & clamping interfaces, fast change fixtures for devices like robot arms, tiny machines, etc. These components make up the majority of the modules. The modular units are connected via a control panel and an industrial cloud, using the 5G module. Data i.e. equipment operation data, sensor data, control instructions, operational procedures, etc. are all included in the communication. The operation of the entire unit is managed by the control system. Supply & clamping interfaces are in charge of positioning and clamping between modular parts as well as connecting power and gas sources. Devices are quickly installed and replaced using quick change fittings. The primary parts may be readily taken apart or put back together since they are removable. After encapsulation, the 5G module may also become a Plug and Play device and be swiftly put together to create a 5G- PnP modular unit.

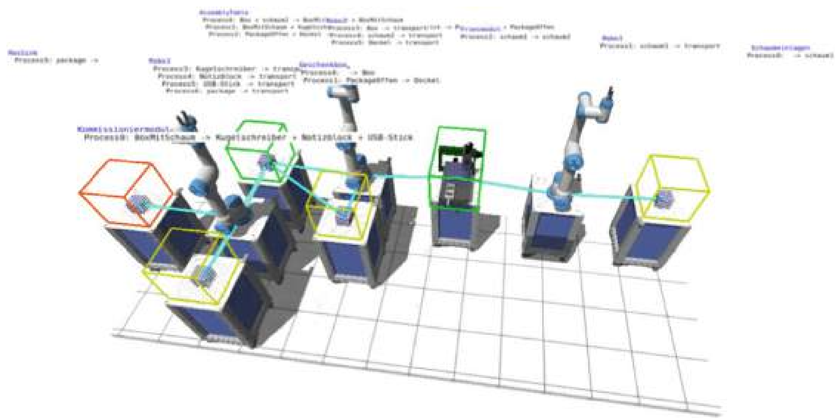

Fig. 6. Simplified exemplary setup (own illustration)

In order to fulfill the PnP between modules and for training reasons, the set of modular units can be properly modified and simplified as an example of PnP application. As seen in Fig. 6, modular parts in the present design comprise storage components, robots, small milling machines, assembly tables, buffer units, and visual identification systems and process flow indicators. For various products, different alternative layouts may be created. For instance, if certain components need to be printed and put together. To monitor and assess the operation status and product quality of the manufacturing line, digital twins are created for the major units, thus generating a bidirectional feedback loop with the physical system and the digital representation. A master control system is included, and manages the overall scheduling of the modular units in accordance with the production process. Figure 7 shows such a setup where we connected a virtual hard-ware environment with the virtual system.

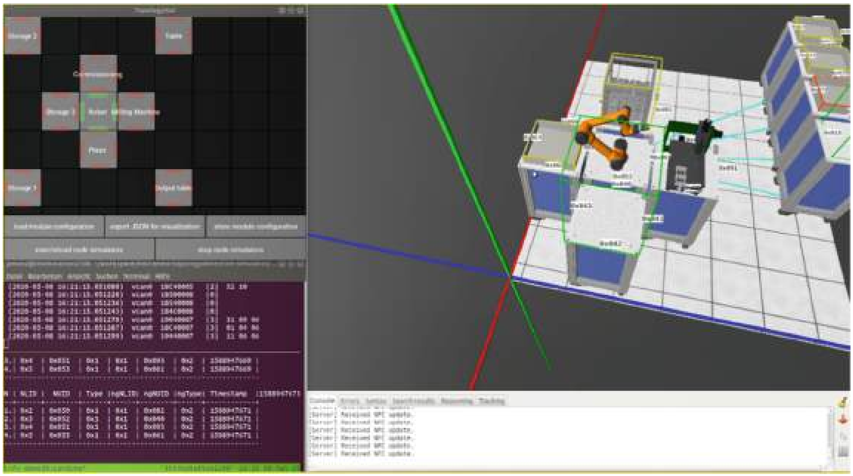

Fig. 7. Set of modular units connected to a virtual hardware-setup (own illustration)

3.2 Artificial Intelligence Technology in Machining: Chatter Identification Tools for Intelligent Manufacturing

In this section, we describe an exemplary scenario how machine learning methods can be used to intelligently solve manufacturing issues in such a connected environment.

In the aerospace, automotive, mobile phone, and almost all other sectors, cutting force, vibration, and stiffness ultimately lead to workpiece deformation, machining mistakes, tool wear, and other undesired material behaviors. Chatter is one of the trickiest issues in real-world machining. For metal cutting, the spindle-tool-workpiece production system frequently generates chatter, a rather intense regeneration/self-excited vibration that has a number of detrimental impacts on machine tools and workpieces. Chatter leaves ripple patterns on the finished surface in addition to lowering machining efficiency and surface quality. Several signals produced during the cutting process, including spindle signals, displacement, acceleration, sound, picture data, cutting force, encoder, and current from the machine's computerized numerical control (CNC) controller, can be used to identify this issue. If one or more acceptable signals are chosen, these signals can be used to indicate chatter. As a consequence, it is possible to keep an eye on the state of the machine and take action to optimize the cutting settings and produce a high-quality surface.

The surface topography of the workpiece, which is connected to machine vibration, may be immediately reflected in image data. To track the state of machine tools that mill, a concept based on the hybrid analysis of multiple signals (cutting force, acceleration, and picture signals) is created. As the machining object, a thin-walled component made of the aluminum alloy AA-7075T6 is used. Then, a streamlined chatter detection index vector is created by mapping the feature values of multi-sensor signals. An enhanced multi-support vector machine (SVM) classification model is trained using this vector to display chatter. The following phases make up the suggested chatter detection approach for intelligent manufacturing, which is depicted in Fig. 8. The following steps are involved: I Signal selection and data acquisition; ii) Signal pre-processing and calculation; iii) Construction of the detection index vector; iv) Building an improved SVM multi-classification model; v) Training the model to achieve chatter identification; vii) Establishing a case study and a database for intelligent manufacturing.

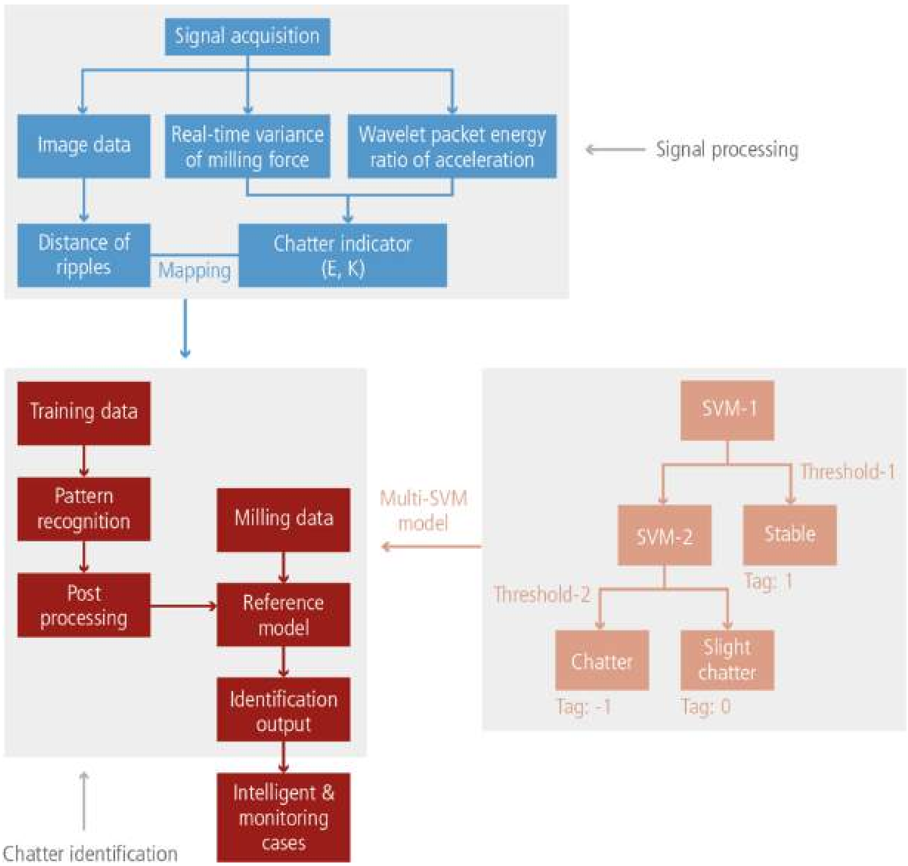

Fig. 8. The process of chatter detection toll (own illustration)

Cutting depth increases cause a significant shift in machine vibration. In order to assure axial cutting depth, the thin-walled component remains installed at an angle as illustrated in Fig. 9, progressively rising to a maximum of 10 mm. In this manner, three different vibration types may be concurrently monitored in one parameter when the cutter feeds in the x direction. The cutting force from the dynamometer's y direction is chosen as the effective signals because the workpiece's primary vibration direction, caused by the horizontal x-cutting route, is in this direction. Similarly, the axial direction of the cutter is the y direction, and the acceleration sensor's z direction is perpendicular to the surface since it is attached to the side of the thin-walled portion. Compared to the other directions, the acceleration signals in the z direction can more accurately indicate the workpiece's vibration status. The process parameters are chosen after taking into account a number of elements. The spindle speed ranges from 2000 rpm to 3500 rpm in 500 rpm increments, while the feed rates range from 0.1 m/min to 0.25 m/min. The milling width ranges from 0.05 mm to 0.2 mm. This collection of settings may ensure that three milling conditions would be created in trials after a total of 64 milling operations.

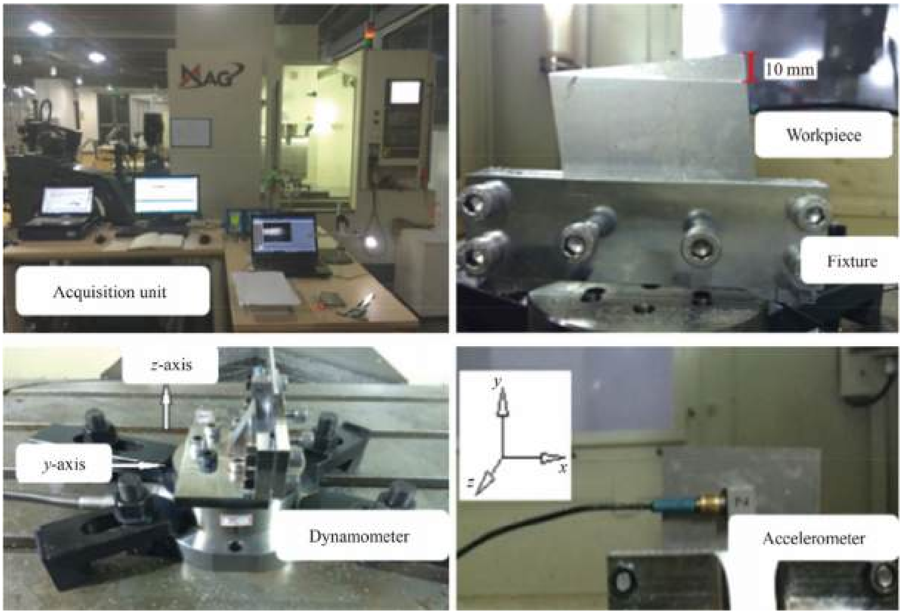

Fig. 9. Experimental scene layout (own illustration)

4 Socio-technical Aspects and Common Marketplace

In the following chapter we want to highlight some of the socio-technical challenges faced during the project. We first want to describe the Sino-German collaboration aspects, discuss interests of the different stakeholders and give an outlook on future growth and different stakeholder integration models.

4.1 International Collaboration

The Sino-German collaboration included industry and academic partners from both China and Germany. After establishing tandem-pairings between the respective institutes of the academic partners, academic exchange and sub-project developments were well coordinated and closely integrated. Through exchange programs, language barriers were reduced and collaboration on scientific challenges were expanded. Yet still, the open exchange of data between the two countries to achieve a common platform had its challenges. Finding a common server infrastructure situated in China and Germany, establishing trust between the partners and enabling the exchange of the required data, working in compliance with the then newly formed Chinese Cybersecurity Law and considering all stated as well as internal interests of the individual partners brought challenges that had to be overcome during the course of the project.

4.2 Socio-economic Potential and Challenges of the Different Stakeholders

Industry partners from both countries offer high-tech products and services. They have the combined potential to validate many platform aspects and offer selective digital services. Having generally superior products regarding efficiency and cost effectiveness automatically open new sales channels through the platform since the selection process would always suggest the superior product according to customer needs. This leads to challenges when different companies offer similar components, where the differentiation is only represented in smaller but potentially significant details. Those details should be adequately represented in the selection process but are sometimes impractical or difficult to assess e.g. previous experiences with the product, availability and quality of services like maintenance etc.

As with any platform solution, platform growth and quality is generated and therefore highly dependent on both growth of the demand as well as the supply side. Demand side has to create a sufficient pull effect to create enough traction for the supply side to increase their offerings. One of the biggest challenges of the platform is to enable the collaboration between different suppliers, but also making them comparable with little effort. Oftentimes comparable information is not readily available or needs to be homogenized therefore posing hurdles to platform entry. In our risk analysis we analyzed, how potential upsides of products might be overstated, while downsides of products might also be described in less detail or not be stated at all.

Companies would have big interests in offering services on the platform that would accompany sales processes in the form of product service systems. We therefore integrate easily accessible application programming interfaces (APIs) to connect existing services into the platform. E.g. one of them being the planning and configuration of delta robots according to product material, piece number and weight as well as a robotic gripper selection dependent on the product geometries and weight. Furthermore, we connected preexisting shopfloor monitoring platforms with their virtual representation on the platform, to have an integrated view for the customer, on the one side handling the planning phase of the production system but also the execution phase, for which further integrated planning and reconfiguration scenarios can easily be validated virtually.

5 Capacity Building

This project showcases a trend that's currently happening in all of industry. Connecting suppliers, integrating different services for products into platforms generates new and different sales channels, accelerates decision processes and helps reducing the time to market of new products. As a byproduct new jobs are being generated due to new market needs always adjusting to customer needs over time. New online sales channels offer opportunities to higher capacity utilization of manufacturing companies, thus enabling lower price offerings, optimizing workloads over all connected companies. Customers of the platform services who want to set up production for new products have fast, cost transparent and, in comparison likely inexpensive opportunities to set up their own production facilities or reconfigure their preexisting facilities. This creates opportunities for new and relevant jobs in the meantime. The platform itself offers a lot of potential for new work, but also connects existing domains of work. Due to its open framework, partners wanting to offer services related to machine tools, automation, consulting, AI and other micro services, data analytics, maintenance, marketing, etc. are all welcomed and increase platform value and traction with each new contribution. As a result, creating a new marketplace of services and products related to customized production system configurations and reconfigurations.

In the new digital era, 5G-based Plug and Play hardware modules not only give full use of advanced technologies, but also meet the needs and trends of the manufacturing industry‘s current development. However, the use of new technologies is also changing the associated requirements for professional skills, which poses a challenge for talent development. In order to provide application scenarios for the rapid establishment and operation of production systems, and effectively cultivate the knowledge and skills of young talents and professionals in IIOT, CPS, AI in the field of advanced manufacturing, as well as provide resources for the retraining and upskilling of employees, it is necessary to create an industry-oriented education and research environment, i.e. to establish student-oriented intelligent manufacturing centers. Therefore, a 5G-based turnkey manufacturing facility will be established in China at AMTC and in Germany at KIT for relevant research and education purposes, so that students can personally experience the practical application of 5G, turnkey systems combined with artificial intelligence methods, learn relevant knowledge and independently design and build modular production lines, gain technical experience, train analytical thinking and innovation abilities, and fully convert the learned knowledge into skills. We now shortly describe the design and progress of the case implementation. Currently, the intelligent factory design is being prepared at AMTC. Construction of modular units has begun, with initial results in application development of 5G modules and software for production line configuration and layout. For example, the 5G module is applied for remote access to a Siemens PLC, which can be used to perform both program download, maintenance and troubleshooting. Then, the modules are installed in the modular units and the master control system for real-time communication between these units to support the transfer of operational data, processing programs and operating instructions, and to solve the docking and coordination problems between units. These application scenarios and tools can provide a foundation for building a complete plant. By learning and using 5G modules and software systems, and comparing the construction and efficiency of this generated solution with the traditional manually developed solutions, students can more intuitively appreciate the advantages and application prospects of 5G and plug and play, and master the relevant knowledge and skills.

6 Summary

In this article we present a Sino-German approach for a factory automation platform in the context of Industry 4.0 and the Internet of Things. We describe technical details of the platform, while also discussing the effects a platform like this will have on the human workforce.

A prototype of a technical solution of a factory automation platform has been implemented during the course of this Sino-German project including basic framework concepts as well as exemplary services for product feature extraction, processing information recommendation, machine tool configuration selection, simulation and validation services, as well as after sales monitoring services.

Through open accessibility, the platform generates new business opportunities for many different stakeholders, enabling new sales channels for production system and component manufacturers, new as well as established companies with new product ideas. Services surrounding and accompanying the product development and production system configuration and -reconfiguration processes as well as monitoring and prognostic elements are manifold. Thus, the factory automation platform creates new digital opportunities for engineering service providers, production system integrators, consulting businesses e.g. in the field of sustainability and circular economy, simulation experts, automation and artificial intelligence experts, creating new and exciting jobs, shifting expertise to the digital realm while collecting data and knowledge for new and more integrated business opportunities.

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Quantification of Uncertainties in Neural Networks

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Abstract. Artificial neural networks only compute point estimates and thus, do not provide the user with a proper decision space. In high-risk use cases, the confidence of the neural network is an important support for decision-making. Bayesian neural networks extend classical deep neural networks with a probability component and allow the user to assess the probability distribution over the prediction. Due to the large number of parameters to be learned, the calculation of the predictive probability can only be performed approximately in practice. In recent years, many methods have been developed to efficiently learn the parameter distributions for Bayesian neural networks. Each of these has different advantages and disadvantages, and thus can be used for different applications. Quantifying uncertainty in the context of neural networks allows the user to interpret the results more comprehensively as well as to assess the risk and therefore makes an important contribution to the user's digital sovereignty.

Keywords: Artificial intelligence · Machine learning · Uncertainty quantification · Neural networks

1 Introduction

In classical machine learning, predictions are usually expressed as point estimates. In a point estimate, the learned model simply returns a single value to the user without informing how confident it is about that prediction. In many use cases, this is acceptable. For example, in the case of movie recommendations on streaming platforms or book recommendations based on books already read, single wrong or bad decisions often have no severe consequences. However, the situation is different in critical application areas of artificial intelligence (AI). In medicine, autonomous driving, or quality testing in industrial production, the financial risks but also, and especially, the impact on humans is significantly greater. Here, a desirable behavior of the AI would be that it provides a confidence to its decision or, in case of very uncertain decisions, signals to the user: "I don't know" or "I am uncertain".

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Developing new methods with this functionality and extending already existing methods with a probability component is the endeavor of the research field *probabilistic machine learning*. In recent years, the focus here has been particularly on deep neural networks (NNs), as they have become the gold standard for many problems, especially in the area of supervised learning. The quantification of uncertainty by the machine learning model allows the user to assess the quality of the prediction and whether the confidence of the prediction is sufficient for the particular use case. Thus, the user is not left completely alone with the algorithm's decision, but is provided with additional information to help him evaluating this decision and take additional actions if necessary. These can include, for example, retraining with new data if the learning algorithm has a high uncertainty in general, or transferring a specific decision to a human review if the algorithm's decision seems too risky. Uncertainty quantification of machine learning algorithms and in particular NNs can thus make an important contribution to digital sovereignty.

The goal of this work is to motivate the quantification of uncertainty for NNs and to present different methods that make this possible in practice. To this end, the different types of probability and the need for approximate methods are first discussed. Afterwards, the Bayesian NN (BNN) is introduced, which is a principled way to realize probabilistic machine learning. The Sects. 3.1–3.6 deal with methods to approximately calculating the posterior probabilities for BNNs. Finally, we discuss the future of the research field and how it can contribute to digital sovereignty.

2 Probabilistic Machine Learning

2.1 Basic Principles

In supervised learning, we always consider a dataset $\mathcal{D} = \{(\mathbf{x}_i, \mathbf{y}_i)\}_{i=1}^{N}$ with N inputs $\mathbf{x}$ and outputs $\mathbf{y}$. While in classical machine learning a function f with parameters θ is to be learned with $f_\theta(\mathbf{x}_i) = \mathbf{y}_i$, in probabilistic machine learning the *output* or *predictive probability distribution* $p(\mathbf{y}|\mathbf{x}, \mathcal{D})$ is to be learned. $p(\mathbf{y}|\mathbf{x}, \mathcal{D})$ is a conditional probability distribution that gives a probability of output $\mathbf{y}$ based on the training data $\mathcal{D}$ and the current data point $\mathbf{x}$. In order to calculate $p(\mathbf{y}|\mathbf{x}, \mathcal{D})$, the parameters of the machine learning model used are also assumed to be probabilistic. By integrating over the probability distribution of the network parameters, $p(\mathbf{y}|\mathbf{x}, \mathcal{D}) = \int p(\mathbf{y}|\mathbf{x}, \theta) \cdot p(\theta|\mathcal{D}) \,\mathrm{d}\,\theta$ can be used to compute the probability distribution of the output $\mathbf{y}$.

Illustratively, by means of the parameter θ, all possible realizations of an NN are considered here in terms of the probability distribution $p(\mathbf{y}|\mathbf{x}, \theta)$. The output of all possible NNs is averaged, with each NN being weighted by $p(\theta|\mathcal{D})$, which represents the probability of different parameter realizations given the training data. Thus, the flexibility and variability in the choice of model parameters is taken into account when calculating the output probability distribution.

In principle, two types of uncertainties must be distinguished in this context. The *aleatoric* uncertainty describes the intrinsic uncertainty within the data used, which is often also referred to as measurement noise. The *epistemic* uncertainty describes the lack of model knowledge, which in our case is reflected in the probability distribution over the model parameters. Based on the available data, for example, different parameter configurations can lead to very similar prediction results. The problem, however, is that the distribution $p(\theta|\mathcal{D})$ can mostly only be calculated approximately. For a large number of parameters θ a high-dimensional integration arises, which can be solved exactly only in exceptional cases. Here, it is often assumed that all relevant quantities are normally distributed in order to simplify the problem.

2.2 Bayesian Neural Networks

If NNs are extended by a probability distribution over their weights, they are called BNNs (see Fig. 1). The concept of BNN has existed for several decades [1], but gained renewed attention in recent years due to the popularity of deep NN. In general, a BNN is characterized not only by model parameters θ, i.e., the weights, but also by a probability distribution $p(\theta)$ over all weights. After successful training, this depends on the learned data $\mathcal{D}$ and becomes the *posterior distribution* $p(\theta|\mathcal{D})$. During the training process, the famous *Bayes' rule* is used to process the information about the training data in order to adjust the distribution $p(\theta)$. The Bayesian rule can be formulated for a BNN as

$$p(\theta|\mathcal{D}) = \frac{p(\mathbf{Y}|\mathbf{X}, \theta) \cdot p(\theta)}{p(\mathbf{Y}|\mathbf{X})} \tag{1}$$

with the training data $\mathbf{X} \triangleq [\mathbf{x}_1 \ldots \mathbf{x}_N]$, $\mathbf{Y} \triangleq [\mathbf{y}_1 \ldots \mathbf{y}_N]$. Here $p(\theta)$ denotes the *prior distribution*, which is assumed to be the initial distribution of weights. This can either already contain information and prior knowledge about the problem or be as general and uninformative as possible. $p(\mathbf{Y}|\mathbf{X}, \theta)$ is called *likelihood*. It describes how well the training data can be modeled with the available model parameters θ. $p(\mathbf{Y}|\mathbf{X})$ is the so-called *evidence*. It serves as a normalization factor and describes the principal probability over the training data independent of the parameter choice. The distribution over the model parameters is adjusted using Eq. (1) as new data becomes available. $p(\mathbf{Y}|\mathbf{X})$ cannot be calculated exactly in general, which is why Eq. (1) can only be solved approximately in practice. The following section deals with different methods for the approximate calculation of the posterior distribution of the parameters of a BNN based on the available data.

3 Overview of Methods

3.1 The Dropout Method

Despite the high performance of deep NN, overfitting to the training data is a major challenge in many use cases. Hinton et al. [2] and Srivastava et al. [3] introduced the dropout method to reduce the negative impact of overfitting for deep

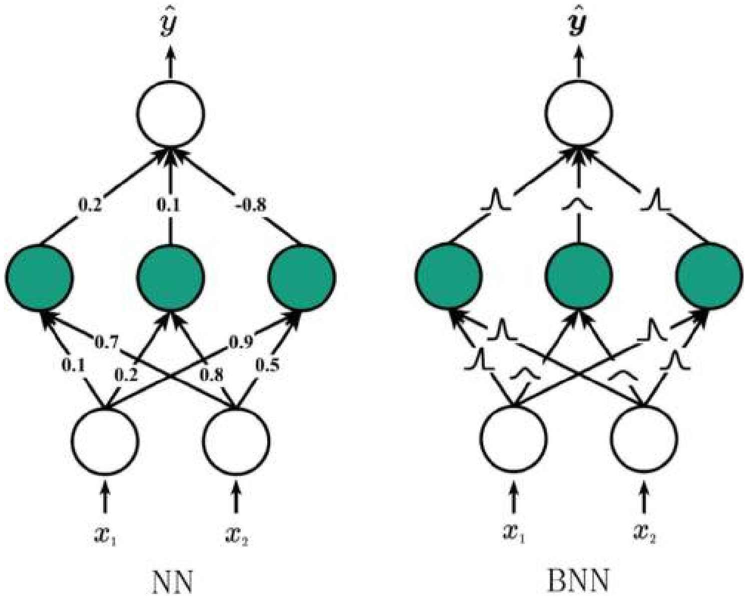

Fig. 1. Illustration of a BNN with a single hidden layer (green) compared to a classical NN. The weights are represented as connections between neurons. The weights of the BNN are associated with a probability distribution to model the uncertainty in the parameter choice, while the weights of the NN are deterministic quantities (Source: own illustration).

NN. Subsequently, many papers have been published dealing with the functionality and theoretical understanding of the dropout method. For example, Baldi and Sadowski [4] proposed to interpret dropout as an l_2 regularizer in the training process of deep NN. Damianou and Lawrence [5], among others, have proved that a deep NN with dropout layers in front of each hidden layer is mathematically approximately equivalent to a Gaussian process. Based on this, Gal and Ghahramani [6] took one step further and prove that by using dropout, training the deep NN can be viewed as minimizing the Kullback-Leibler divergence (KL divergence) between the approximate probability distribution of the deep NN and the posterior distribution of the underlying Gaussian process. And by using dropout before each hidden layer, regardless of the type of hidden layers (fully connected, convolutional, or recurrent), the deep NN can be considered as BNN with uncertainty quantification.

The application of the dropout method is very simple: First, a dropout layer with an appropriate dropout rate must be added before each hidden layer, regardless of whether it is the first layer after the input layer or the last layer before the output layer. In addition, a regularizer must be chosen for the dropout layer. The authors recommend l_2 regularization if the goal is to have uncertainty increase far from the data.

For normal deep NNs, the dropout layers are only active during training and are switched off in the inference phase. In the case of BNNs, the dropout layers remain active during the inference phase to provide an estimate of the probability distribution instead of a point estimate for a prediction. This means that even though the deep NN has exactly the same input, it can make different predictions because the structure of the network is slightly different for each inference due to the dropout layer. Therefore, for each input, we can get n different output values for n times inference. Gal and Ghahramani [6] proved that the mean and standard deviation of these n output values are approximately equal to the mean and standard deviation of the posterior Gaussian distribution of the underlying Gaussian process with the given input. In practice, the mean is considered as the final prediction for the given input and the standard deviation quantifies the uncertainty for this prediction. Considering that the estimation of the probability distribution is based on the multiple repetition of the inference process, the method is also called *Monte Carlo Dropout* (MC Dropout).

A disadvantage of MC Dropout is that this method introduces new hyperparameters, for example, the dropout rate for the dropout layers. To address this issue, Gal et al. published a new method called Concrete Dropout in [7] that allows automatic exploration of the dropout rate and allows deep NNs to dynamically adjust their uncertainty quantification as more data are observed. This variant saves the user time for fine-tuning the dropout rate. However, the training and inference of this method requires more resources than normal dropout-based BNN.

3.2 Ensembles

As mentioned in the previous section, in MC Dropout the prediction is summarized from the multiple repetitions of the network's inference processes with the same input, and in each inference the network structure is slightly changed due to the active dropout layers. In this regard, MC dropout could also be interpreted as *ensemble* of multiple deep NNs [3], where the individual NNs differ due to the dropout layers but still share most of the parameters. Lakshminarayanan et al. propose in [8] to use an ensemble of several differently initialized NNs with the same structure directly as an approximation to the Bayesian inference model instead of MC dropout. The advantage is that additional hyperparameters, such as dropout rates for each dropout layer, are avoided. This interpretation motivated the authors to investigate ensembles under the name *Deep Ensemble* as an alternative approach for uncertainty quantification of deep NNs.

In Fig. 2 we show the difference between MC Dropout and Deep Ensemble. In the case of Deep Ensemble, all the networks in the ensemble have the same structure, but have been randomly initialized differently for training, and the data points in the dataset are randomly shuffled for training each network.

Based on the Deep Ensemble method of Lakshminarayanan et al., Pearce et al. proposed a new method called *Anchored Ensembling* in [9]. Compared to Deep

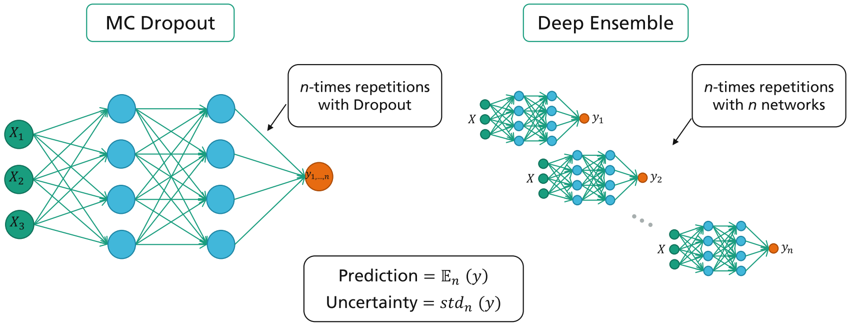

Fig. 2. Difference between MC Dropout and Deep Ensemble (Source: own illustration).

Ensemble, Anchored Ensembling regularizes the parameters of the deep NN with assumed prior probability distributions. The authors report better performance and more accurate probability estimation. However, the prior probability distribution must be carefully chosen. In our experiments, the performance of this method has been shown to be sensitive to the selected hyperparameters.

3.3 Variational Inference

In addition to the previously presented simple methods for approximate Bayesian inference, *Variational Inference (VI)* attempts to formulate and solve the Bayesian inference problem as an optimization problem. In this section, we will first explain the mathematical principles behind this method and then introduce some useful tools for the application of VI.

As explained in Sect. 2.2, a common problem with BNN is that the evidence $p(\mathbf{Y}|\mathbf{X})$ is difficult or even impossible to calculate exactly. To avoid the intractability of the evidence in Eq. (1), VI adopts a simpler surrogate function $q(\theta)$ to approximate the true posterior probability distribution $p(\theta|\mathcal{D})$. The measurement of the similarity between two probability distributions is the KL divergence

$$\mathrm{KL}(q(\theta)\|p(\theta|\mathcal{D})) = \int q(\theta)\left[\log \frac{q(\theta)}{p(\theta|\mathcal{D})}\right] \mathrm{d}\,\theta \ . \tag{2}$$

Here, the optimal surrogate function for the approximation is exactly the function that minimizes the KL divergence, i.e.,

$$q^*(\theta) = \arg\min \mathrm{KL}(q(\theta)\|p(\theta|\mathcal{D})) \ . \tag{3}$$

Bishop et al. [29] proved that minimizing the KL divergence is equivalent to maximizing the *evidence lower bound loss function (ELBO)*

$$\begin{aligned}\mathrm{ELBO}(q(\theta)) &= \int q(\theta)[\log p(\mathbf{Y},\theta|\mathbf{X}) - \log q(\theta)]\,\mathrm{d}\,\theta \\ &= \int q(\theta)\log p(\mathbf{Y}|\mathbf{X},\theta)\,\mathrm{d}\,\theta - \mathrm{KL}(q(\theta)\|p(\theta))\ . \end{aligned} \tag{4}$$

Here, (4) is equal to the term $\log p(\mathbf{Y}|\mathbf{X}) - \mathrm{KL}(q(\theta)\|p(\theta|\mathcal{D}))$. Given that the KL divergence is always non-negative, it can be seen that $\mathrm{ELBO}(q(\theta))$ is always less than or equal to the *log-evidence* $\log p(\mathbf{Y}|\mathbf{X})$, which explains the name of this loss function. Since the evidence is constant and independent of θ, maximizing the ELBO automatically leads to minimizing the KL divergence. Consequently, the optimization problem in Eq. (3) can be rewritten into

$$\begin{aligned}q^*(\theta) &= \arg\min \mathrm{KL}(q(\theta)\|p(\theta|\mathcal{D})) \\ &= \arg\max \int q(\theta)\log p(\mathbf{Y}|\mathbf{X},\theta)\,\mathrm{d}\,\theta - \mathrm{KL}(q(\theta)\|p(\theta))\ . \end{aligned} \tag{5}$$

In Eq. (5), it can be seen that the intractable evidence $p(\mathbf{Y}|\mathbf{X})$ is not required as the posterior distribution $p(\theta|\mathcal{D})$ is avoided. Instead, we only need to process the known priori distribution $p(\theta)$ and the likelihood $p(\mathbf{Y}|\mathbf{X},\theta)$, which are easier to handle. In this way, we simplify the inference problem into a solvable and tractable optimization problem.

If we examine Eq. (5) again, we notice that the first part of the equation corresponds to a maximum likelihood estimator and the second part of the equation adds a prior part to the ELBO loss function to make the estimation based on the prior knowledge, hence it resembles the maximum a posteriori estimator in this aspect.

Several open-source libraries for Bayesian inference and probabilistic modeling for machine learning have already been developed. Table 1 includes a comparison and summary of the most popular probabilistic programming language tools. In our work and research, we usually use Pyro and Tensorflow Probability (TFP), depending on the deep learning frameworks we choose. The two libraries are preferred because they are under active development and are associated with well-known frameworks for deep NNs.

3.4 Laplace Approximation

The *Laplace Approximation* is based on a relatively simple idea [10]. Often, only the region around the maximum is of interest in the posterior distribution. Provided that this maximum is known, the distribution in its neighborhood can be approximated with a Taylor-series expansion. The maximum θ_{MAP} can be determined by classical training via gradient descent. For the Taylor-series expansion up to the second order we can obtain

$$\log p(\theta|\mathcal{D}) \approx \log p(\theta_{\mathrm{MAP}}|\mathcal{D}) - \frac{1}{2}(\theta - \theta_{\mathrm{MAP}})^{\top}\mathbf{H}\,(\theta - \theta_{\mathrm{MAP}}) \tag{6}$$

Table 1. Current open-source libraries for Bayesian inference and probabilistic modeling. All libraries support VI and MCMC methods.

Libraries	Backend	Comments
Edward [18]	Python;Tensorflow	Not active for a long time
Stan [19]	C++	Python interface PyStan under development
PyMC3 [20]	Python; Theano	Theano is no longer active
Pyro [21]	Python; PyTorch	Recommended for use in PyTorch projects
TFP [22]	Python; Tensorflow	Recommended for use in Tensorflow projects

with the Hessian matrix $\mathbf{H}$. The first term of the Taylor-series expansion vanishes as we expand around a maximum. The Taylor-series expansion around θ_{MAP} thus results in a normal distribution of the form

$$p(\theta|\mathcal{D}) \approx p(\theta_{\mathrm{MAP}}|\mathcal{D}) \cdot \exp\left(-\frac{1}{2}(\theta - \theta_{\mathrm{MAP}})^{\top}\mathbf{H}\,(\theta - \theta_{\mathrm{MAP}})\right) \tag{7}$$

with Hessian matrix being the inverse of the covariance matrix. However, this approximation of $p(\theta|\mathcal{D})$ is not normalized and thus not yet a valid probability density. With the normalization factor of a multivariate normal distribution we obtain

$$p(\theta|\mathcal{D}) \approx \frac{1}{\sqrt{|2\pi\mathbf{H}|}} \exp\left(-\frac{1}{2}(\theta - \theta_{\mathrm{MAP}})^{\top}\mathbf{H}\,(\theta - \theta_{\mathrm{MAP}})\right) \;. \tag{8}$$

A limiting factor is the calculation of the Hessian matrix, since it can quickly become very large for a huge number of parameters. In practice, therefore, further approximation methods are often used to calculate $\mathbf{H}$. This allows the method to be used even for large NNs. An advantage of the Laplace approximation is that it can also be applied to already trained NNs to add an uncertainty component in a post-hoc fashion. Since the method approximates the true distribution only locally, the approximated distribution can in principle deviate strongly from the true one. In most cases, however, especially for large data sets, satisfactory results can be achieved with the Laplace approximation.

3.5 Kalman Filter-Based Approaches

While VI treats the Bayesian inference problem as an optimization problem using the ELBO loss function, many other researchers attempt to treat this problem as a filtering problem using Kalman filters. Classical Kalman filters are applicable only to linear systems; however, many variants extend them quite well to nonlinear systems. Singhal and Wu presented the first algorithm in 1989 that uses the extended Kalman filter to train BNN [11]. Compared to the normal gradient-based and batch-based methods, such Kalman filter-based methods proved to be much more effective than the standard backpropagation in terms of

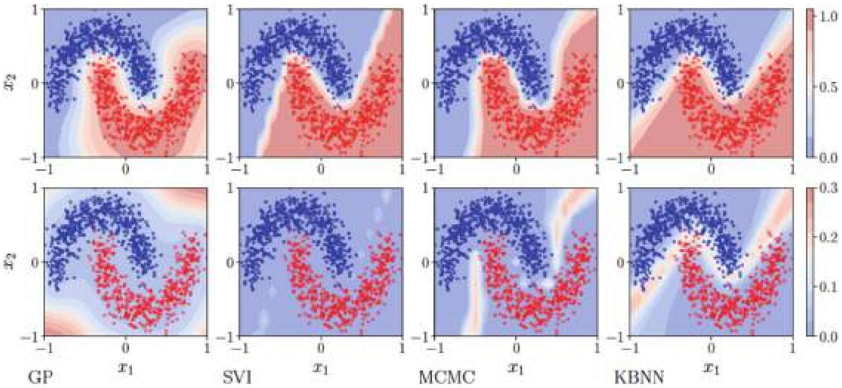

Fig. 3. Comparison between Gaussian Process (GP), Stochastic VI, MCMC method and KBNN on a synthetic classification dataset. The first row shows the predictions for the binary classes. The second row shows the uncertainty quantification of the predictions in the data space. The three BNN variants have similar higher uncertainty in the transition region between classes (Source: own illustration).

the number of training epochs [12]. Watanabe and Tzafesta proposed a different approach in [13], in which the weights of the networks are assumed to be Gaussian distributed and the mean and variance of each weight are updated using an extended Kalman filter, but which requires local linearization for updating the neurons in hidden layers. This method was extended by Puskorius and Feldkamp [14] to allow for layer-wise correlated or even network-wide correlated neurons.

To avoid linearization, Huber proposes in [15] the so-called *Bayesian Perceptron*. Even though it is restricted to a single neuron, this work proves that a closed-form computation of the mean and covariance matrix of the posterior weight distribution is possible, provided that the weights are assumed to be Gaussian distributed. Based on the Bayesian Perceptron, Wagner et al. in [16] extended this method from a single neuron to a multilayer perceptron (MLP) and called it *Kalman Bayesian Neural Network (KBNN)*. In this work, a closed-form forward and backward propagation of the weight distributions in each layer is introduced. This method shows its advantages in terms of online learning capacity and learning efficiency compared to other popular BNN methods such as VI and MCMC. Figure 3 shows a comparison between different BNN methods. Among them, KBNN has the best learning efficiency. Chen et al. introduced another method [17] in 2021, which uses the ensemble Kalman filter to handle the measurement noise in the data and to account for it in the uncertainty quantification.

3.6 Markov Chain Monte Carlo

Another popular and well-researched approach for Bayesian inference to learn BNNs is the *Markov Chain Monte Carlo (MCMC)* method. A Markov chain describes a process in which the current state depends only on the last state. Under certain assumptions and starting from an initial state, a Markov chain always converges to a stationary distribution. Once this distribution is reached, all further states will correspond to this distribution. However, it is in general not known a priori how many steps along the Markov chain are necessary until the stationary distribution is reached.

In the context of Bayesian inference, Monte Carlo methods without Markov chains form a broad class of sampling algorithms that use repeated random sampling to generate samples from complex posterior distributions. Rejection sampling [23] is the basic Monte Carlo method to generate samples from a given distribution. However, rejection sampling is very inefficient because the samples are uncorrelated. Combining these sampling methods with various algorithms to construct Markov chains for the desired probability distribution (e.g., the posterior distribution of weights in BNNs) yields MCMC methods whose stationary distribution are proportionate to the desired posterior distribution. Hence, the samples of the stationary distribution represent an approximation of the posterior distribution and thus, characteristic parameters of this distribution such as the mean or the variance can be calculated.

One of the earliest MCMC methods is the Metropolis-Hastings algorithm [24,25]. Many improvements have been proposed for that, such as Gibbs sampling [26], hybrid Monte-Carlo or Hamiltonian-Monte-Carlo (HMC) [27]. A major extension of HMC is the No-U-Turn Sampler (NUTS) [28], which usually works much more efficiently. The libraries listed in Table 1 support MCMC methods as well as VI.

4 Conclusion

In this paper, we have presented BNNs as an approach to achieve uncertainty quantification in the field of deep learning. Similar to other Bayesian inference problems, BNNs assume a prior probability distribution of the weights of the NN and attempt to learn a posterior distribution of these weights using the available data.

Several methods have been proposed in the literature to realize the training and inference of BNNs as efficiently as possible. Dropout and ensemble methods are among the simple variants, where the learning and inference of BNNs is considered as aggregation through an ensemble of different networks. However, the weights are considered to be deterministic. In the other, "real" Bayesian methods, the weights of the NN are modeled as random variables. Variational inference formulates the learning task as an optimization problem, which is approximately solved by using the ELBO loss function. In comparison, MCMC algorithms use Markov chains to draw samples from the posterior distribution of weights. While the Laplace approximation utilizes the local Taylor-series expansion to obtain an additional uncertainty quantification on trained NNs, Kalman filter-based methods propose to formulate the calculation of the posterior distribution of the weights as a filtering problem in which the weights are recursively updated.

Compared to conventional NNs, BNNs offer advantages in active learning, causal inference, out-of-distribution detection, and security-related use cases thanks to the capability of uncertainty quantification. In the future, we focus on the scalability of different methods and the applications of BNNs in novel fields, such as reinforcement learning and verification of AI. We believe that uncertainty quantification will be crucial for increasing the reliability and explainability of AI systems, which are key elements for digital sovereignty at the level of robustness and trustworthiness.

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A Final Word

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Having reached the end of this book, we will now draw a provisional conclusion and give an outlook on further projects. As already mentioned in the introduction (Hartmann and Shajek 2022, this volume), the Institute for Innovation and Technology (iit) has been working on the future of work for many years. In the publications of the 2010–2020 decade (in particular the volumes by Botthof and Hartmann 2015; Wischmann and Hartmann, 2018), the main aim was to present fundamental theories on the then still new topic of Industry 4.0, to initiate a socio-political discourse, and subsequently to compile and focus on practical examples from the field of research and development.

In the early 2020s, a new substantive focus was then set on digital sovereignty and outlined in its complexity with two edited volumes (Hartmann 2021, 2022). In the present publication, we now put the workplace in the center and focus on the opportunities, possibilities, and limits of digital sovereignty from a wide range of academic disciplines, for different industries and in different parts of the world. What becomes clear is: Digitalization now permeates almost every aspect of our workplace, it has complex and multi-layered effects, and it can only be analyzed here by way of example.

At the same time, our work is characterized by a fundamentally optimistic view: Digitalization can enable sovereignty in the first place or promote sovereignty and open up the scope for action, for example, with the help of digital assistance systems (see the contribution by Bächler and Behrendt 2022, this volume) or through the possibilities of digitally supported education (see the contributions by Kanyane 2022, this volume and Windelband 2022, this volume). In addition, approaches are presented to positively shape the change towards digital work. The underlying assumption here is that there is also freedom of choice in the digital workplace and no technological determinism (see also Botthof and Hartmann 2015). All facets resulting from the dimensions transparency and explainability, confidence and freedom of action for people, and technology and organization (Hartmann and Shajek 2022, this volume) can be positively influenced.

This focus inevitably leaves out some aspects that will, however, also be of central importance for the (digital) future of work: From a work psychology perspective, these include questions of psychological stress resulting from the changed working conditions and corresponding occupational health management issues (some individual aspects are, however, dealt with in the article by Mayer et al. 2022, in this volume). But there are also many aspects arising from the digitalization of workplaces for the interactions of employees, e.g., for the cooperation between supervisors and their employees. In this context, these are common conditions for success in digital work (see, e.g., Busch-Heizmann et al. 2021). Digital work platforms are also given far less consideration (cf. Hartmann and Shajek 2022, in this volume), which might be a consequence of the

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editors' one-sided German perspective. Questions of the cognitive-enhancement debate also remain largely untouched.

However, the topic of the future of work has not yet come to a close for us: We are already planning another volume with which we want to deepen the understanding of digital sovereignty at the corporate level (or any other type of organization). In particular, the publication intends to support management-level actors in designing strategies, products, structures, and processes to improve digital sovereignty. Topics include external challenges to organizational autonomy, such as the nature of digital products and markets, legal frameworks, and industry policies related to digital markets and products. Managing digital sovereignty at the enterprise level shall be addressed, with topics including, e.g., skills development or risk management as well as product and service design in support of digital sovereignty. Also planned are case studies to illustrate conditions for success.

We hope therefore to be able to provide one or two impulses in the future that will at least maintain and, if possible, promote the ability of companies and employees to act in the face of the constantly expanding capabilities of digital technologies.

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Alexandra Shajek and Ernst Hartmann in November 2022.

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