Competence development and learning assistance systems for the data-driven future

Wilfried Sihn, Sebastian Schlund
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Introduction

Companies that already have a good understanding of the technological possibilities of digitalisation and automation and consider them as a "must have", recognise, that their employees are becoming one of the most important digitalisation factors. Without the involvement of their own employees, the implementation of digitalised and automated solutions cannot create sustainable benefits. Employees become unavoidable the "bottleneck" of digitisation projects and companies are encouraged to invest in their employees. But why are they becoming the most important digitisation factor? Digitalisation and automation are significantly changing job profiles, especially in direct value-added areas, but also in administrative areas. In addition to technical know-how, new conceptual and social skills are required for digital work and collaboration. Employees must be able to adapt to changed work environments, such as automated value creation processes or digitally provided information at the workplace, through their individual characteristics such as awareness, knowledge and skills.

With the conference proceedings under the guiding theme "Competence development and learning assistance systems for the data-driven future", the Scientific Society for Work and Business Organisation (WGAB) would like to contribute to these emerging challenges. The contributions of all authors presented, provide insight into innovative concepts and research results. They do not only provide a beneficial input for scientists, also practitioners get useful methods on different levels.

We would like to thank all participating authors for their exciting and important contributions, which will certainly lead to valuable input for thoughts and discussions and thus bring us closer to the answers to the most urgent questions of our time.

Vienna, September 2021

Wilfried Sihn and Sebastian Schlund

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Successfully developing workplace-related skills using digital assistance systems

Wilhelm Bauer, Maike Link, Walter Ganz

1. Digitising the world of work as a driver of new opportunities for developing workplace-related skills

In the "Future of Jobs Report 2020", 94 per cent of the managers interviewed stated that they expect their staff to carry on with further training programmes and continue gaining new qualifications. Apart from the high percentage, it is the increase when compared to 2018 that is remarkable. Back then, 65 per cent of those surveyed expected their employees to continue with further training (Zahidi et al., 2020). Following the COVID-19 pandemic, the pressure on staff to gain further qualifications is rising. "Teaching future skills [1]will become more important than ever in Germany over the years to come. Even before COVID-19 took hold, disruptive business models had changed the world of work beyond recognition. The crisis resulting from this pandemic is accelerating digital change and influencing existing business models with ever greater force" (Kirchherr et al., 2020, p. 4). The survey shows that "in the short term, the focus is on the most urgent deficits in training, notably key digital qualifications, mainly in the fields of 'digital interaction', 'digital learning' and 'digital literacy'" (Kirchherr et al., 2020, p. 5).

Besides the challenges brought about by the coronavirus, the ongoing, technology-induced transformation process is one reason for increased requirements in the development of skills. At the same time, the design of the workplace is changing in this context. It is becoming more context-adaptive, intuitive, networked and supported by assistance systems (see Figure 1). This article concentrates on the increasing significance of digital (learning) assistance systems.

[1] Future skills are those skills that, over the next few years, will become ever more important for working life and participation in social aspects in all sectors. They can be subdivided into "key digital skills", "technological skills" and "key non-digital skills" Kirchherr et al. (2020, p. 5).

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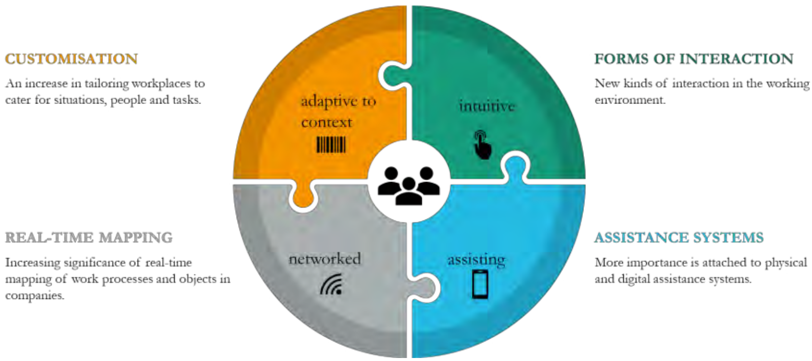

Figure 1: Workplace trends (Fraunhofer IAO)

The changing set-up of work often results in a change in the distribution of skills between people and technology and the need for adapted employee skill profiles (cf. (Ganz et al., 2019; Ittermann & Niehaus, 2018; Windelband & Dworschak, 2015)). The extensive debates in science and industry on this subject reveal both challenges and opportunities for companies. The company's goal is to design an intelligent work system that benefits from increased productivity and optimisation of resources. Technologies, such as artificial intelligence (AI), offer huge added value potential in this respect (Behrens et al., 2021). In order to develop the potential for change in terms of technical, organisational and social aspects, an intelligent learning system needs to be created at the same time that is directly linked to the work system. The use of artificial intelligence (AI) can promote needs and personnel-specific training which, at the same time, enables the improvement of the underlying technical system (reciprocal learning). The best scenario will be that both the work and learning systems are positively influenced by AI-assisted learning technology.

There has long been a debate in both research and in everyday life on the challenges posed by "lifelong learning" and "work-related learning". Digitisation and new AI-assisted learning technologies are now able to reach these goals and help staff in the sense of "learning workers" in order to improve the efficiency of developing workplace skills. Innovative learning technologies refer to new ways of developing workplace learning. With the help of new learning technologies, the previous external control of learning modules and content is expanded to include the possibility of self-governed learning that is flexible in terms of both time and location. By tailoring the learning units and making it possible to learn in different locations, it will be possible to continuously develop skills and acquire qualifications that are specific to the individual and job role (Jenewein, 2018; Sammet & Wolf, 2019; Sauter & Sauter, 2013).

Creating a work system that promotes learning can, for instance, be supported by the use of a digital learning assistance system to convey content (Pokorni et al., 2021). Corresponding digital learning assistance systems will add a learning infrastructure to work, thereby creating work-related learning spaces in which a person can learn in a self-controlled and self-determined manner (Dehnbostel, 2020).

"Digital learning assistance systems" is a term that comprises, on the one hand, digital assistance systems that are used primarily to assist with work, and also include functions for imparting information and further training. On the other hand, digital assistance systems are created and used solely for further training within the company and without having an assisting function in a person's job. A study revealed that roughly one third of the companies surveyed stated that they use learning assistance systems with the aim of getting their staff to gain further qualifications on an ongoing basis (Klapper et al., 2019).

This article aims to highlight the potential and challenges of digital (learning) assistance systems for workplace-related learning and to show the extent to which the introduction of corresponding systems can lead to further training in the workplace. We will initially present the joint project "TransWork" and the investigation that was carried out as part of the project (Chapter 1.1). This is followed by a sketch of the criteria for developing a successful introduction process with corresponding learning assistance systems (Chapter 1.2). Finally, the question will be examined as to the role that can be played by artificial intelligence (AI) in in-house further training measures (Chapter 2.1) and the challenges currently confronting the creation of AI-assisted learning (Chapter 2.2). Chapter 2.3 looks at two possible research and development projects. Finally, the development and planning of symbiotic interaction (human-machine) are examined in Chapter 2.4 and the ways in which mutual reciprocal learning in the interaction between humankind and assistance systems are analysed. The final section looks at the conclusions which can be drawn, offering an outlook on the development of workplace-related skills featuring artificial intelligence (Chapter 3).

1.1. The use of digital learning assistance systems

As part of the joint project "TransWork"[2] (TransWork - transformation of work through digitalization), research was carried out on digital tools and assistance systems. Here, digital assistance systems were investigated in terms of both their use as a working tool as well as their potential as a learning aid.

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[2] The "TransWork" project was funded by the Federal Ministry of Education and Research under the "Work in the Digitalized World" programme (funding reference 02L15A160) and supervised by PTKA, an independent service unit of the Karlsruhe Institute of Technology. The responsibility for the content of this publication is retained by the authors. For more information, please go to: www.transwork.de.

The objective of the research carried out was to develop decision-making tools that primarily assisted those responsible for the standardisation process in assessing, selecting and reintroducing digital assistance systems.

The following topics were investigated:

- What digital learning systems are employed for which areas of use?
- What success criteria are key to introducing and using (learning) assistance systems?
- How is work transformed by the introduction of assistance systems (this does not constitute a part of this article, please see (Bauer et al., 2021; Link, Schnalzer, & Hamann, 2020))

As part of the TransWork project, a working definition was created first of all, which reflects the diversity of the different types of digital assistance. Accordingly, digital assistance "systems are computer-based systems that assist people with information intake (the way they perceive it), processing the information (decision-making) and carrying out work. A difference can be made between the extent, type and goals of support" (Link & Hamann, 2019, p. 684) in accordance with (Apt et al., 2018; Blutner et al., 2007; Busse et al., 2018; Link & Hamann, 2019).

In twelve collaborative projects from the main funding source "Work in the Digitalized World", the procedures for the development and introduction of digital assistance systems were examined in 16 use cases[3]. Here a digital assistance system was used in one use case primarily as a learning tool, in six use cases it was used as a working tool and in nine use cases it was used as both a working and learning tool, depending on the area for which it was intended (Link, Schnalzer, & Hamann, 2020).

The ten assistance systems that offer the users learning opportunities are discussed below. An overview of the selected (learning) features of the learning assistance systems investigated is presented in the morphological box below, which was (Niehaus, 2017) expanded on the basis of, and adapted to, (Apt et al., 2018; Hacker et al., 1995) the investigation. The main points identified among all learning assistance systems investigated are in italics.

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[3] Data basis: 15 guided interviews with company representatives from ten collaborative projects and project documentation from two collaborative projects. Evaluation: qualitative, category-guided content analysis of interview transcripts and project documents and publications.

Feature	**Attribute**			
Assistance form	Learning tool		*Working and learning tool*	
Sector	*Industry/manufacturing industry*	Service	Construction	Different industries
Target group	*Employees without responsibility for staff*		Employees with responsibility for staff	
Learning aid	Basic information	*Advanced information*	Knowledge query	
Usage interval	Once	*Ongoing*	Selective	Periodic
Support objective	Compensatory	Retentive	*Widening*	
Qualification requirements	None		*Instruction (formal/informal)*	
Adaptivity	*No*			
Documentation of learning success	*Yes*		*No*	

Table 1: Features and attributes of the ten digital learning assistance systems that were investigated (own source, *note: all stated attributes were found at least once in the assistance systems under investigation)

The evaluation showed the diversity of the possible applications (learning/training), the set-up (learning assistance/learning and work assistance) as well as the objective (basic knowledge/further information/knowledge query/documentation of learning successes) in different sectors (industrial/service/construction/industry-independent).

The digital learning assistance systems that were surveyed are mainly used for ongoing further training. This is shown in the characteristic attribute *further information* as the predominant learning aid, an *ongoing* usage interval as well as a support objective of expanding knowledge.

However, the learning assistance systems also partially provide support for *retaining* existing knowledge or for *compensating* for gaps in knowledge. Depending on the situation at work or the person using the assistance system, it can be used either *selectively* (with problems), *periodically* (regularly for recurring working processes) or to enable new members of staff to *learn the ropes*. The latter option allows the standardised preparation of information via the learning assistance system, in order to convey relevant aspects of work activities in a comprehensible manner and to ensure complete initial instruction. Most of the digital learning assistance systems observed are used at work on an *ongoing* basis. None of the learning assistance systems examined was able to cater to the member of staff *adaptively*, e.g. by adjusting the speed at which it was delivered. According to information provided by the interview partners, a brief in-house *introduction* (formal or informal) is required in most cases, in order to use the learning assistance systems. In fact, some of the learning assistance systems can be operated intuitively, and do not need any briefing. A formally organised training session, for instance by outside experts, was not required in any of the cases surveyed (Link, Schnalzer, & Hamann, 2020).

The criteria relevant for success with the introduction of the digital assistance systems from both a company and employee perspective for the surveyed projects and the learning-specific prerequisites will be examined in the next chapter.

1.2. Planning aspects for the successful introduction process of digital (learning) assistance systems

Success and inhibiting factors were identified across all sectors during the investigation of the introduction process of digital assistance systems (irrespective of whether learning or working tools). The results were not surprising. They reflect estimates which are known from the introduction procedures of other IT systems or automation projects (see comparison (Ganz, Kremer, et al., 2021)). Here, there still appears to be a lack of transfer of scientific findings into entrepreneurial practice.

To summarise, the following assessments concerning the success in introducing digital assistance systems can be deduced from the study:

1. The availability of a technical infrastructure, such as the connection of the systems to an existing IT landscape, is a fundamental factor in the success in the introduction. Furthermore, the company-specific choice and adaptation of the required hardware and software is an important task which can also have an effect on the acceptance of the new systems by staff.

2. If staff are involved in the choice and introduction, the technical, organisational and social requirements for the system can be detected at an early stage and incorporated into the selection (requirements and needs analysis). This means that domain experts, staff from the HR and IT departments as well as the works council must be involved (interdisciplinary project team). A pilot project provides the ideal opportunity to test the new system as well as obtain feedback on the functions and procedures, so that mistakes and challenges can be detected and eradicated before the system is rolled out in certain departments or throughout the company. In such a test and trial phase, ‘multipliers’ can also be trained to pass on their experience and impart knowledge about the system to colleagues in the event of a wide-scale introduction.

3. Another aspect for the successful introduction of digital assistance systems is, on the one hand, the qualification of the project team, which needs to have the technical, organisational as well as methodical knowledge, in order to assist in the selection and implementation of the learning assistance system. On the other hand, thought needs to be given to ensuring that staff are qualified for the new system.

In spite of the demand that the assistance systems are easy to operate and can be used intuitively, not all assistance systems can be operated by every member of staff. This means that, in addition to creating acceptance and willingness to use the system, it is necessary, first and foremost, to check whether instruction in the system is required (qualification and development of skills) (for further TransWork results, please see (Link, Schnalzer & Hamann, 2020); for criteria from reference works, please see as an example ((Deutsches Institut für Normung e.V., 2019; Klapper et al., 2019; Sauter & Sauter, 2013; Schenk et al., 2016)).

4. When introducing learning assistance systems in particular, the survey showed that is necessary to check the existing work organisation and processes for the existence or creation of learning periods. It is often the case that employees do not have enough time for further training during their normal working hours. Whereas, for instance, there are generally fixed and mobile end user devices in assembly areas, active breaks can be created here for workplace learning due to the high clock rates and production specifications. In other sectors, for instance in the care industry, there are none or hardly any digital assistance systems around that could be used to aid learning. At the same time, our interview partners from the collaborative projects also stated that there is hardly any time to learn during working hours because of the number of tasks that need to be completed. Learning takes place during off-peak times or after work.

Learning by means of digital learning assistance systems can only take place if learning incentives are in place during normal working, learning periods are available and can be taken up by the individual and learning certificates are recognised. Factors to aid learning that are most often used during the introduction are summarised in the following Figure 2.

Figure 2 Steps for a successful introduction process (Fraunhofer IAO)

The introduction of digital learning assistance systems with artificial intelligence to help the functions is a way to offer employees tailored help in the learning process. As already shown in Table 1, none of the digital learning assistance systems from the funding priority has adaptive functions that aid customised learning. In future, artificial intelligence will enable learning to become faster, simpler, more effective and more efficient with the help of automated evaluations of learning behaviour and needs as well as tailored learning paths and learning content.

The following section takes a look at the question as to what extent artificial intelligence is already integrated in further training methods and the potential and challenges posed by this technology.

2. Artificial intelligence as a supporting learning technology for workplace-based learning

The possible use of artificial intelligence (AI) in learning systems is gaining importance in both science and industry. AI-assisted learning systems have the advantage that both the learning process and content can be compiled and planned for the individual according to their needs. This results in highly personalised and efficient "on-the-job" training.

We now wish to present current trends in AI as a learning technology and to illustrate the possible ways in which AI-aided learning can be integrated into workplace learning. We will then move on to outline potential opportunities for and current challenges in using AI as a learning technology aid.

2.1. Use and potential of artificial intelligence in further training programmes

Researchers have been working on the use of AI to support learning processes since the 1970s (e.g. (Aleksander et al., 1990)). It now seems that the technological maturity of AI has made a practical implementation possible in (adaptive) learning systems.

A study by Siepmann shows that AI has found its initial applications in vocational training. Around 34 per cent of companies stated in the benchmark study that they have or are planning different methods, such as adaptive training systems. The analyses also show that there was a significant increase in both actual and forecast figures between 2019 and 2020 (Siepmann, 2020). According to assessments in the HolonIQ Artificial Intelligence & Global Education Report, AI is the fastest growing education technology and will be used extensively throughout the world (primarily in the USA and China) over the coming years (HolonIQ, 2019). This use is backed up with considerable potential for development across all sectors (Pinkwart & Beudt, 2020).

The term "artificial intelligence" includes different technical processes and extensive potential for applications when viewed as a learning technology. In a survey of companies carried out in 2020 by the mmb Institute for Media and Competence Research, in which they were asked what role different AI technologies would play in learning programmes over the next three years, roughly 39 per cent of respondents saw AI-aided learning analytics and adaptive learning as being "very important" (mmb Institut – Gesellschaft für Medien- und Kompetenzforschung mbH, 2020). This shows, on the one hand, the relevance of AI support for improved learning forecasts in the field of further education. On the other, the results show that, above all, learning paths tailored to the learner's requirements are a required function in further training (Siepmann, 2020).

When planning an AI-based learning assistance system, a closer look must also be taken at the application level. A difference must be made in training between granularity and the target group. For instance, Pinkwart & Beudt differentiate between the micro-, meso- and macro-level (Pinkwart & Beudt, 2020).

	Learner	**Trainer**	**Organisation**
Micro-level	Adaptive training software	Task to determine the level of difficulty of the training programme	Dynamic availability of resources, e.g. learning content
Meso-level	Monitoring one's own learning success	Analysis of group learning processes	Assistance in the time it takes to plan a training programme
Macro-level	Long-term ePortfolios, fit to job profiles	Further development as a trainer, lessons learned as regards factors of success	Monitoring of qualitative aspects and revision of training programmes

Table 2: Training application scenarios using AI (according to (Bernd et al., 2020))

If AI is used to assist detailed and specific training and learning processes for specific time periods at the micro-level, the use of AI at the meso-level is geared towards the use in medium-term learning scenarios with automated analyses of learning results. These can then be used to identify individual learning patterns and to develop adaptive learning systems. (Pinkwart & Beudt, 2020, p. 8) explain that AI-aided assistance technologies [are located] "at the meso-level of AI assistance […] that are not specifically tailored to the training context but which can be used there, such as text-to-speech generators or image recognition software […] or other digital assistance systems geared to the specific topic that is not primarily intended for short-term training purposes, but rather e.g. used as integrated learning and working tools in the medium term". This assessment also coincides with the responses from the companies that were studied during the TransWork project. They, too, emphasised, that they were looking for assistance solutions, in particular, ones that could be used as both learning and work tools.

At the macro-level, AI technology can, for example, help in the strategic planning of further training strategies and modules to develop goal-oriented, workplace-related skills.

2.2. Challenges in creating AI-based learning

The authors stress that nowadays systems are used mainly to assist with specific learning processes in integrated learning and assistance systems (at a micro- and meso-level) (Pinkwart & Beudt, 2020). Nevertheless, the potential of ongoing use (macro-level) appears to be extensive and could be used in designing courses (e.g. use of a hybrid approach – human-AI methods), technically (e.g. adaptive micro learning programmes) and by HR departments (e.g. course certificates). One reason why these assistance systems have not been used to a great extent at the macro-level to date is the so far hardly fulfilled prerequisite that available training content is available in a modular and fine-grained manner, meaning that a lot of work will have to be done first to support the customisation learning content and formats for the individual. Moreover, adaptive training courses require precise domain models, automated evaluations of the learning solutions as well as didactic models that are technically feasible. Here the technical and didactic development is still in its infancy (Pinkwart & Beudt, 2020).

If the use of AI-aided learning assistance systems offers the possibility to create further training courses with greater efficiency, this then meets with criticism on the part of both learners and trainers. It is primarily the dominance of AI over the education process and thus the restriction of a free and a self-determined learning process that is viewed critically. Where previously mainly "classic" AI-aided training technologies were created based on rules and knowledge, statistical machine learning methods are currently being tested and used. However, the methods mentioned above and the ensuing control over the learning process are difficult for the learner to understand. As the control and understanding of the learning process are of elementary importance for the learner, as are the learning assistance systems used, it is to be expected that primarily hybrid, cognitive AI methods will link data-driven findings with knowledge-based explanations in the future. Consequently, a learning process is then created which is transparent and logical, so that the learner understands how the respective learning paths and content have come about.

AI-aided learning processes are both expanded and made more complex by the learning aspect of AI in the process. Statistic/learning AI training technologies are based on extensive user data generated via machine learning. System models are continually improved by means of educational data mining procedures using AI-aided learning assistance systems. This results in the opportunity to train both the technical system and the human learner (Pinkwart & Beudt, 2020).

The success factors described in Chapter 1 for the introduction process of digital assistance systems to assist in developing workplace-related skills also apply to the technical expansion of systems by means of artificial intelligence. This is shown for example in the study by (Siepmann, 2020), where companies state the reasons why they are against the use of AI, notably the current state of technology, the complex implementation or non-compatible infrastructure, data protection and security as well as the concerns of management, works council and HR department.

Consequently, we wish to refer again to the experiences gained from TransWork: the early involvement of those who will be using the system and key stakeholders (i.e. board of directors, management, works council, HR department, IT) promotes both the acceptance as well as the willingness to use when implementing AI-aided assistance systems.

We would like to point out here that, regarding the success factors of introducing innovation projects such as e.g. assistance systems, there is often a gap in the transfer of knowledge, especially among SMEs. This is not only evident in the introduction of digital (learning) assistance systems but also when it is a matter of introducing AI solutions in the company (Bauer et al., 2019; Ganz, Friedrich, et al., 2021). Research offers numerous guides on the human-centred introduction of digital assistance systems. In this context, it is necessary to examine the transferability potential of these guides to the topic of AI and to broaden criteria specific to the topic such as, for instance, how to explain the ways in which artificial intelligence works. In addition, new and innovative transfer formats need to be developed. One example of a new and successful transfer format is "Popup Labor BW"[4]. The pop-up lab is a temporary workshop where companies, especially SMEs, can learn about new technologies. It is low-threshold in its approach and takes place in different locations around the federal state of Baden-Württemberg (BW).

2.3. Current examples of research and application

As previously mentioned, the topic of AI-aided assistance systems for supporting workplace-related further training programmes is becoming increasingly the focus of various research and development projects. Two project ideas are outlined below as examples to illustrate, in particular, the breadth of potential in the application of AI for developing job-related skills.

One example is the NAWID[5] project funded by BMAS on the "use of AI-aided assistance and knowledge services in company-specific training spaces, taking into account heterogeneous worlds of values in demographic change". Digitisation

[4] https://www.iao.fraunhofer.de/de/forschung/organisationsentwicklung-und-arbeitsgestaltung/popup-labor-bw.html
[5] https://www.nawid-projekt.de/dasprojekt-ziel/

prompts increased demands on the willingness of employees to change and internal and external qualifications. Lifelong learning will be required even more, and the respective content will need to be made accessible according to context, while, at the same time, references to the context will continually be redefined. Consequently, a high degree of flexibility will be needed in terms of providing learning programmes. The project addresses two core areas of action and structure in companies: cultural change in the digital transformation and key issues of demography in work and qualification processes. In learning and experimental spaces, the introduction and use of assistance and knowledge services as well as applications of artificial intelligence are tested in the project by means of models and examples.

The joint model development and testing of AI systems in this research project is carried out for various use cases that address tailored learning in the office and on the shop floor. In one application case, for example, a knowledge-based system is developed and tested that is intended to provide adaptive learning support at the micro-level. The systems extend an e-learning programme already in existence by adding user-adaptive support material that is intended, in particular, to monitor and manage the learner's own learning process (e.g. the learner reflects on their learning progress, checks their own understanding of the learning content that has been presented). As a result, the system supports self-organised learning, which is particularly relevant for workplace and lifelong learning scenarios.

ARIBUS is one of the partners actively involved in this project. In this use case, the transfer of knowledge geared towards a particular activity in the workplace in relation to "Industry 4.0" is explored and implemented as a pilot project with the help of a new learning environment. Basically, this is intended to help in training and learning a complex assembly process. Supporting adaptive learning is achieved by the fact that the system combines relevant domain knowledge as well as information on the learner's individual skills and previous experience with data-based analyses (e.g. sensor-based recording of the learner's interaction with the system, component movements, etc.). The system is then supposed to recognise the learner's issues and offer help in real time. When developing the components necessary for the hybrid AI system (e.g. domain model, didactic knowledge, fine-grained learning materials) collaboration was undertaken with employees, members of works' councils as well as trainees and apprentices, in order to incorporate their practical knowledge into the development of the system (see www.nawid-projekt.de as well as (Pinkwart & Beudt, 2020)).

The second example presented here is an R&D project from the AI Innovation Centre "Learning Systems and Cognitive Robotics", an initiative of the Fraunhofer-Gesellschaft applied research organisation[6]. The Stuttgart-based Fraunhofer

[6] https://www.ki-fortschrittszentrum.de/de/projekte/dafne.html

institutes IAO and IPA work together with companies on joint projects, in order to implement AI technologies on a broad scale into the manufacturing sector and service industries. In this context, the Fraunhofer Institute for Industrial Engineering (IAO) worked together with Trumpf, a German industrial machine manufacturing company, on AI support for field representatives and developed a prototype of a digital assistant for field representatives to optimise administrative tasks.

A field representative is confronted with numerous tasks during their daily routine, irrespective of the sector in which they are employed, from the preparation for and the follow-up of a customer meeting, to the development of new customer and product-relevant information as a result of taking over a new sales region or the launch of new products. Scenarios were developed and assessed in collaboration with the project partner Trumpf, in order to make these tasks more tangible. Incorporating AI into the task of "documenting a customer meeting" was seen to be especially useful and important. This work often takes place in the evenings, when reports and records of meetings are written up, e-mails sent as well as other administrative tasks.

A dialogue-based language assistant with a control function is intended to improve the situation for these tasks, insofar as it records all relevant customer information and key points of the meeting immediately after the meeting has taken place by means of AI-aided voice input (see Figure 3). Notes are then transferred into the CRM system after they have been manually checked. When the voice input is finished, the subsequent AI-aided activities like forwarding praise, sending product information or suggesting follow-up meetings are then carried out.

Other AI-aided assistance functions such as e.g. preparing suggested e-mails to send to the customer based on previous meetings and the customer profile in question form part of the concept. In addition, an intelligent link with the address stored in the database is intended to create dynamic suggestions for customer meetings in the vicinity of where the field representative has their next sales call.

Consequently, the digital assistant is supposed to help the field representative to use add value to the time spent on administrative tasks supported by AI. The assistance system allows the field representative to carry out admin and communication tasks easily at any time, whether in the office or out on the road, and saves up to 10 to 15 per cent of their time as well as reducing the workload.

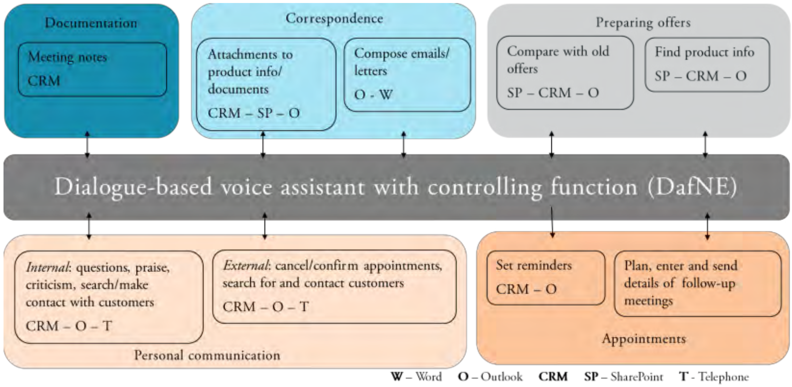

Figure 3 Digital assistant for field representatives to optimise time spent on administrative tasks (Dukino, 2021)

Besides these functions, ideas are currently being discussed as to how this assistance system can be further developed. For instance, it is feasible that the assistance system could provide brief learning units for the sales representative to listen to on their journey to a customer meeting. With the help of so-called "learning nuggets", the employee would be presented with information such as minutes from the previous meetings, new company or product information that may be of interest to the customer, or products manufactured by the target company. This lets the employee recall important information which they can put to good use during the customer sales call and the customer feels appreciated (Dukino, 2021; Link, Dukino, et al., 2020).

As shown in the examples, various scenarios and prototypes are currently being developed and tested, such as creating new functions in assistance systems where the use of AI adds value. This naturally includes the fact that Research and Development are increasingly concentrating on AI as an aid in learning technology. One topic on which Research and Development has recently focussed their attention is the potential of developing digital assistance systems that encourages two-way, reciprocal learning.

2.4. Reciprocal learning during the work process

The catchphrase "specialisation scenario" or even "tool scenario" was long favoured as the model in which emphasis was put on the fact that technical innovations should support people and not substitute them or make their tasks redundant (Windelband & Spöttl, 2011). Possible solutions are increasingly being explored in line with the technical progress of AI as to how artificial intelligence can support the symbiotic interaction between employees and machines (assistance systems). Symbiotic interaction aims to form the assisting functions of artificial intelligence in such a way that it helps humans to accomplish highly complex tasks carried out at work (Daugherty & Wilson, 2018), thus allowing reciprocal learning to take place, where both the "learning system" and the person achieve added value – the learning system by expanding and improving its databases and the human through the working and thus learning environment, which is conducive to learning and, above all, is individually tailored to the individual's requirements (Huchler et al., 2020).

A categorised table of man and AI interaction was compiled by Huchler and based on previous studies such as levels of autonomy (Ahlborn et al., 2019), with an assessment of the interaction between man and artificial intelligence. The scores given were on a scale from 0 (poor quality of interaction) to 1 (high quality of interaction) (see Table 3).

Stage	0 Man	0.5 partly man	1 Man & AI	0.5 partly AI	0 AI
MMI quality	MMI poor quality	MMI mediocre quality	MMI high quality	MMI mediocre quality	MMI poor quality
Learning	**Split learning:** The human learns separately from the technical system, the quality of machine learning is not improved by MMI	**Asymmetric learning I:** The human's knowledge and experience are not used to improve the system's learning process; corrections are only done on a sporadic basis	**Reciprocal learning:** The MMI is configured to promote the learning aspect, meaning that the system and human help each other to learn; high degree of learning quality	**Asymmetric learning II:** The system learns separately, the human can only manipulate the technical learning process, and learn in the best case either by chance or autonomously in the process of using it.	**Hindered learning:** The system learns "behind the scenes", the human factor is irrelevant

Table 3: Potential learning scenarios in human-AI interaction (Fraunhofer IAO in accordance with (Huchler, 2020))

According to Huchler, poor quality interaction occurs either as a result of "split learning", where the human is learning but the system does not experience any improvement, or during "hindered learning", where the system learns in the background but the human factor is in danger of being made redundant. The aim should actually be to create a dynamic learning relationship between the human and the machine, in order to improve both human and machine skills (Huchler, 2020). "Here the AI systems learn on the basis of explicit human instruction or by observing human actions, whilst the human can learn at the same time by using precisely those AI tools" (Pinkwart & Beudt, 2020, p. 17). This type of workplace-related learning is also referred to as "two-way" or even "reciprocal" learning (Mayrhofer et al., 2019).

Initial technical applications are currently being developed and tested in pilot projects and pilot plants. Apart from collaborative robots, digital assistance systems can be used, for instance, for assembly and servicing, to test different learning scenarios. Researchers at Vienna University of Technology (TU Wien) studied split tasks between assembly workers and collaborative robots in the "Industry 4.0" pilot plant, thus testing various learning scenarios between humans and machines. In this way, junior workers were able to learn from both senior staff and cobots, while the cobot learns how to handle new fault scenarios from either senior staff or other cobots (Mayrhofer et al., 2019).

3. Conclusion and outlook on using artificial intelligence to develop workplace-related skills

The introduction outlined how work will develop in the future. It will get "smarter" (cf. Figure 1). New forms of interaction between humans and technology will fundamentally change the way we work everywhere. Learning systems, robotics and virtual as well as augmented reality mean that work and business processes will be mapped transparently in real time in the future. Nevertheless, it is only the targeted combination of new technologies, modern organisational and work structures as well as qualified and motivated staff that will enable the full potential of this transformation to be realised.

This transformation process will change the skills required from employees. Besides creating a basic understanding of technology, in order to assist in the acceptance of the use of AI, an understanding of processes and systems as well as the establishment of new skill profiles (roles) will be necessary. Training programmes will be required that are geared more towards specific target groups and particular needs, the content of which is supported by user-centred learning assistance systems.

Greatest potential is seen in the partnership between humans and machines in the sense of a symbiotic interaction. In contexts of education, hybrid human-AI systems are becoming increasingly important, and AI can be integrated into existing training systems significantly more than used to be the case (Pinkwart & Beudt, 2020). The goal should be a differentiated approach towards the building up skills. On the one hand, it trains employees in understanding and handling AI applications, including further training, and, on the other, educates employees, who are concerned with the development, training and updating as well as adaptation and statement of performance of AI solutions (Ganz, Friedrich, et al., 2021).

As already seen, particular attention should be given to getting staff involved during the process of introducing assistance systems. This must involve the key stakeholders at the implementation stage. During the preparation of the introduction stage, it is crucial to check what skills the stakeholders have and require in order to accompany the project. One way in which stakeholders' skills can be built up is, for example, the "Learning World" in the Future Work Lab[7]. The Future Work Lab, part of the Fraunhofer IAO, is an innovation lab for work, people and technology, and exposes companies, associations, employees and trade unions to the development of future-oriented work concepts. Part of the lab is the Learning World ("Lernwelt") which serves as a skills development and advisory centre, where all employees and interest groups can get more information, obtain further qualifications and together discuss possible developments of future working environments. This includes, for instance, the impact of digitalisation, new requirements concerning skills and qualifications, latest learning concepts as well as the organisation and assessment of working environments in a way that promotes learning and is geared towards the individual employee.

However, the Future Work Lab is not just a demonstration and advice platform. Prototypal solutions are promoted, such as intelligent support via AI-aided assistance systems, with the goal of developing a workplace that represents a combination of "affective computing" (emotion AI) and a digital assistance system. The AI-aided assistance system not only recognises processed objects, for instance, during an assembly process, and delivers the information required for the working steps, but also reacts situationally to the employee's emotions which it recognises. If the system recognises that the process is working above or below its capacity, it recommends possible countermeasures to the employee. Where the system is working below capacity, it can suggest, for example, "micro-lessons" on current company topics, and the employee can be trained at their workstation. Overall, the aim is to minimise excessive demands by means of targeted support, to avoid excess capacity, to support workplace-related learning as well as to encourage motivation and improve productivity (Wimmer & Bangali, 2021 (in print)).

The analyses carried out by TransWork have shown that a substantial dynamic exists in the application in terms of the development and introduction of learning assistance systems. Nonetheless, topics that need to be researched and developed are still apparent. Among the outstanding R&D topics, there is the question as to how emotions can be taken into consideration in intelligent educational technologies. These could then become advanced "learning companions", which take into account the level of stress or frustration affecting the learner. Furthermore, there is potential in using AI for longer-term strategic planning and teaching and further training. Even VR-based and AR-based training technologies may benefit from incorporating AI, such as analysing activity patterns and tailored responses to activities in virtual worlds. The question remains as to how processes and methods for modularising educational content as a prerequisite for customisation can come into widespread use (Pinkwart & Beudt, 2020).

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[7] https://futureworklab.de/

The aforementioned research and development topics are important fields of research that are being investigated at Fraunhofer IAO, both now and in the future.

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This is how we learn

A Best Practice Case of Qualification in SMEs for Work 4.0

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Digitalization is forcing small and medium-sized enterprises (SMEs) to rethink their work and production processes. Initiated by this process, the organization of production and employees are subject to change. As a result, the job profiles of employees are changing and expanding, as well as the way how knowledge is imparted. Innovative and digitized formats should be integrated into existing training programs and presented in a way that is suitable for use on mobile devices. Therefore, suitable and target group-specific teaching/learning formats are needed that support participative methods and digital collaboration.

For this purpose, a digital teaching and learning format for the application area of automotive engineering in SMEs was designed. This prototypical teaching/learning format was created and evaluated in an iterative process through the participation of the potential users and taking into account existing usability criteria. The two methods used to evaluate the format were Think-Aloud and focus group, the results of this evaluations are presented in this paper. The results show that when evaluating the teaching/learning format, the test subjects mainly refer to the usability criteria of DIN ISO 9241-110, the structure of the course and the information content of the course. Recommendations for the creation of future digital teaching and learning formats for SMEs are derived from these findings.

1. Reorientation of education and training 4.0 through digitalization

Information technology has permanently changed private life, working and learning. Digitalization is making its way into all occupational fields and defining new industries and business models (acatech 2016; Heim et al. 2016). In particular, the manufacturing industry and its branches of industry as well as their inherent work processes are affected by the digital transformation. Digitalization not only creates new job profiles, but also redefines the requirements for existing occupational fields. Accordingly, the needs of employers and employees are changing with regard to training and further education measures in order to do justice to the technological transformation and its effects (Poschmann 2015). Various studies see the top priority of the digitally transformation in the context of work in the ability of lifelong learning (acatech 2016; Ingenics / Fraunhofer IAO 2014). As a result, ex-

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isting training and further education content must be adapted to meet the requirements of digitization for both the learners and the teaching/learning content (Lichtblau et al. 2015). Work-process-integrated and highly flexible forms of learning are focused and should be able to be dynamically and efficiently adapted to changing work processes, requirements and learning needs (Kuhlmann/Sauter 2008; Hofert 2016; Melzer/Bullinger 2017). In order to make work conducive to learning, classic teaching/learning formats are no longer sufficient since they can only be adapted to changing processes with great effort and cannot be used interactively on mobile devices (Dombrowski/Wulbrandt/Fochler 2019). The focus of corporate educational work is the question of how and in which framework work can be designed to promote learning and skills, taking into account the personal dimension (Dehnbostel 2018). This offers the possibility to design teaching/learning content in an individualized way: Learners are in the focus and the process of imparting knowledge is simultaneously understood as a process of social exchange and interaction between learners. Following this development, learners take more responsibility for the learning process and knowledge is constructed and integrated based on existing experiences (Wegener et al. 2011; Meissner/Stenger 2014). The adaptation of appropriate delivery methods and teaching/learning content can be enabled by digital learning and contribute to developing professional skills such as situational, critically reflective, creative, and productive learning and teaching (Arnold et al. 2018). The focus here is primarily on content transfer through the use of digital tools or teaching/learning concepts (Aust et al. 2019; Dombrowski et al. 2019).

Taking these possibilities and the needs of the teachers and learners into account, two factors critical to success can be identified: The user-centered development of the teaching/learning format with the involvement of the teachers and learners and, building on the findings of the user-centered development process, the usability with regard to the presentation and operation of the teaching/learning format (Zeiner-Fink et al. 2018). Both of these factors require an approach that i) captures the needs and wants of learners and ii) an iterative evaluation process ensures that these needs have been realized (Feldhoff et al. 2019). This paper presents a digital teaching/learning format that was evaluated and created following the process described by Feldhoff et al. (2019). Furthermore, recommendations for the creation of future teaching/learning formats are derived from the evaluation.

2. Focus on learners: user-centered approach to evaluating a teaching/learning format

Based on the user-centered design process following DIN EN ISO 9241-210 (ISO 9241-110: 2020) and the service design process according to Leimeister (2012), a digital teaching/learning format of an automotive manufacturer in the field of high-voltage awareness is evaluated (Feldhoff et al. 2019). This digital course included various media such as audio content, animated videos, animated and interactive diagrams as well as learning assessments. It is planned to integrate this course into future teaching activities of universities of cooperative education in the field of automotive engineering. The teaching/learning format which gets evaluated was initially created by an IT service provider without involving the learners. It should be used in training and further education. The original analog course, on the other hand, included occasional videos and relied largely on face-to-face instruction. The evaluation was carried out in two evaluation phases (see Figure 1) using the methods "thinking aloud" and "focus group".

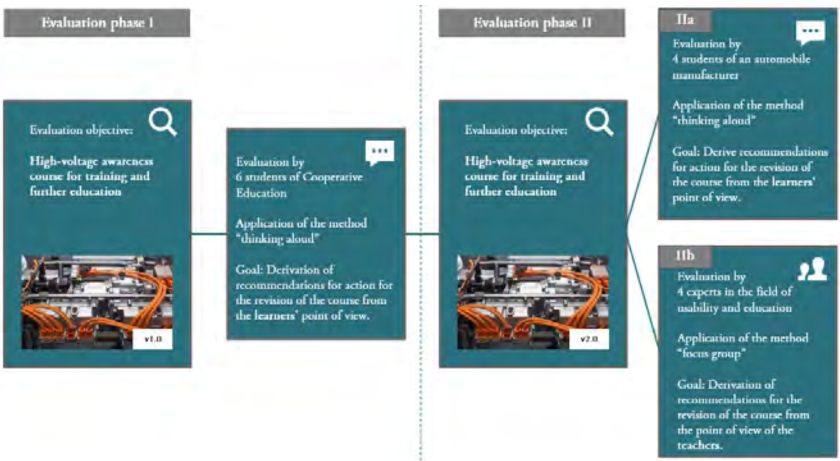

Figure 1: Representation of the evaluation phases

2.1. Methods

In order to evaluate the high-voltage awareness course in terms of usability and the quality of the learning content, the qualitative methods "thinking aloud" and "focus group" were used in an iterative procedure. By using the method of thinking aloud, a test person verbalizes his or her thoughts during the execution of the experiment (Jääskeläinen 2010). The "focus group" method, on the other hand, represents a moderated group discussion. Based on a guideline, the experimenter moderates the discussion, which is usually led by experts on a predefined topic

(Steward et al. 1990). The methods were chosen because, in addition to problem detection from the user's point of view, they also enable a diagnosis of potential causes, from which specific recommendations for action to correct the identified problems can be derived. In addition, the technology affinity of all participants who used the method of thinking aloud was assessed and compared using the ATI scale, to ensure that the participants' skills in using digital devices were comparable. (Franke et al. 2019).

2.2. Test procedure

The test procedure included two iterative evaluation phases (Figure 1). Evaluation phase I included the method of thinking aloud. Six students from the course of vehicle technology (w = 0, m = 6) from a university of cooperative education were selected randomly. All students did not yet have an academic degree, completed their studies as a dual system and studied vehicle technology in two different years, whereby the course content for high-voltage awareness was completed by all students. All test subjects showed a comparable affinity for technology and experience in dealing with digital end devices. The processing time for the digital teaching/ teaching format was set at 45-60 minutes. Each student was assigned an experimenter. The entire test run was recorded and then transcribed with MAXQDA. The problems identified by the subjects were then compared by a small group of four usability experts (over four years of experience in usability testing) from the field of education to eliminate duplications and misconceptions. The revision of the teaching/learning format based on the knowledge gained from the first test run was tested in evaluation phase II. This phase contained both an evaluation using the method of thinking aloud (evaluation phase IIa) and a focus group (evaluation phase IIb). Phase IIa included four test subjects (w = 2, m = 2) from a German automobile manufacturer. It was ensured that the education and technical affinity of the test subjects was comparable with the cohort from the first evaluation phase. The test procedure and the learning task to be completed were identical to evaluation phase I.

In addition, the revision of the high-voltage awareness course was evaluated by a focus group (evaluation phase IIb). The focus group consisted of four usability experts (different to those from the comparison of the identified problems after phase I and IIa, w = 2, m = 2) from the field of education. The participants were not familiar with the findings from evaluation phases I and IIa. The focus group was conducted in order to additionally address the needs and requirements from the perspective of the teachers and with regard to the usability and technical design of the course. The high-voltage awareness course was completed by all participants prior to the focus group evaluation. In addition, the contents of the guideline were communicated and participants were asked to take notes on potential problems during the course. The moderation of the group was ensured by using a guideline. The recording was transcribed and analyzed using MAXQDA.

3. Results

The respondents' statements from evaluation phase I were assigned to the deductively formed categories "technical implementation," "course content," and "platform design" using qualitative content analysis.

The technical implementation addressed, among other things, quantifiable usability criteria of DIN ISO 9241-110 (ISO 9241-110: 2020), such as suitability for the task, self-descriptiveness, and ease of learning (with respect to the learnability of system operation). In addition, the technical quality of the audio-visual (A/V) content presented was evaluated (volume, resolution, etc.). The topic area "course content" referred to the presentation, linking and interactivity of the teaching/learning content, i.e., whether the content was presented in a comprehensible way and whether there was a perceived benefit for the learners from using the digital course. Identified problems in the area of "platform design", on the other hand, related only to the presentation of the platform's audiovisual content (videos, use of color, design elements, etc.). The distribution of the identified problems can be seen in Figure 2.

A total of 50 problems (multiple responses taken into account and summarized) were identified with an average of 35.6 problems per learner ($s = 8.3$). Problems were, for example, the incomprehensible course structure (course content), missing dialog options (technical implementation – suitability for the task) or poor contrast values (platform design - use of color). These problems were assessed and weighted by usability experts from the field of education. Six problems were removed during the review process or assigned to other problems. For example, two respondents identified the problem "lack of information about the diagram" and "insufficient explanations about the diagram". The two problems were combined to "task-relevant information is not available for diagrams (suitability for the task)".

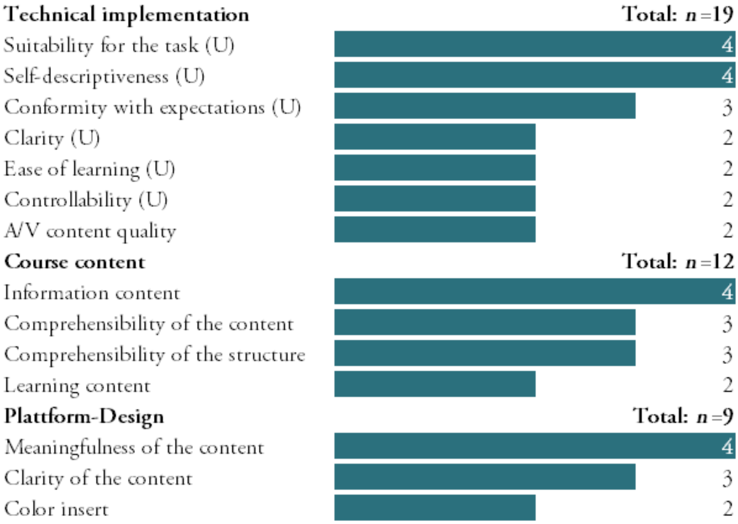

Figure 1: Evaluation phase I - distribution of the absolute numbers of the identified problems in the first evaluation run (only mapping of at least two mentions); (U) represents usability criteria of DIN-ISO 9241-110

Four problems were directly related to the complexity of the learning content and were excluded for further consideration. Most of the problems were identified in the category "technical implementation" with regard to usability. All test persons criticized the self-descriptiveness of the teaching/learning format (interaction buttons without prompt character, unconventional design of the interaction buttons, etc.), the suitability for the task (missing functions, dialog steps do not fit the task) and conformity with expectations (incomprehensible or unknown abbreviations, inconsistent design). The application of the method of thinking aloud enabled not only the identification of the problems from the learners' point of view, but also a diagnosis of the causes, which was used to derive specific proposals for solutions or recommendations for action for the revision of the tested teaching/learning format. A revision of the system by the IT service provider was based on 37 recommendations for action.

The revision of the teaching/learning format was tested in evaluation phase II. The overview of the identified problems in evaluation phase IIa can be seen in Figure 3.

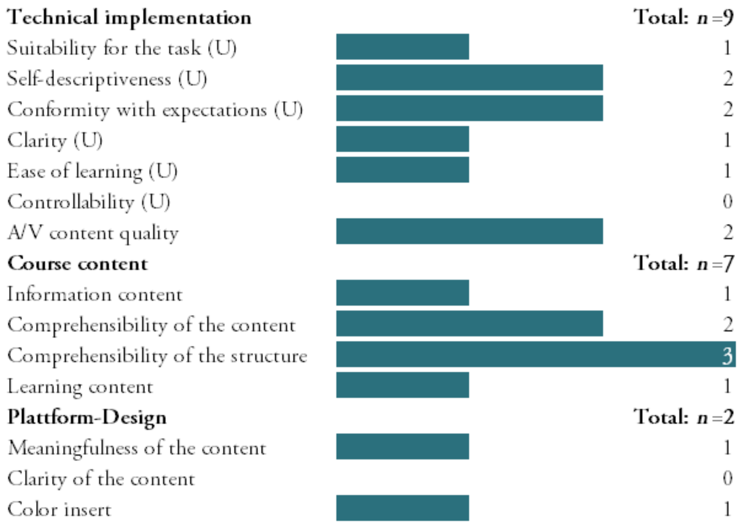

Figure 2: Evaluation phase IIa - distribution of the absolute frequencies of the identified problems in the second evaluation run; (U) represents usability criteria of DIN ISO 9241-110

A total of 18 problems (multiple responses considered and summarized) were identified, an average of 16.7 problems per learner (s = 2.8). After the review by the team of usability experts from the field of education, 17 problems remained in the revision of the teaching/learning format. Four of these problems were not considered further because they were directly related to the complexity of the learning content (identical problems as in the first phase). Eight of the problems identified related to changes made during the revision, and six of the problems identified in the second phase were not identified by the first cohort (e.g., lack of interactivity of the tabular presentations, arrangement of course content, etc.).

The problems identified by the focus group were assigned to the same categories as the problems from evaluation passes I and IIa. Figure 4 shows the problems identified.

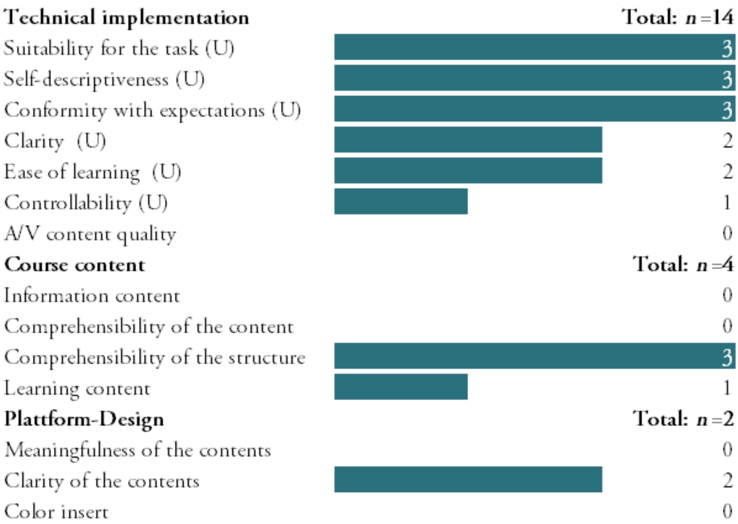

Figure 4: Evaluation phase IIb - distribution of the absolute frequencies of the identified problems of the focus group; (U) represents usability criteria of DIN ISO 9241-110

The focus group of four participants identified a total of 20 problems. These problems were not verified by another group of experts.

3.1. Consolidation of the evaluation results

The identified problems of the focus group were compared with those of the evaluation of evaluation phase IIa by a team of experts from the fields of usability and education. Ten problems with similar causes were identified by both groups (e.g., consistency of pictograms and abbreviations, availability of course content downloads, lack of interaction options). While the remaining four problems of the learner evaluation were mainly related to the information content and the comprehensibility of the course content, the focus group was able to identify further usability problems in particular, but also referred to content-related problems of the course structure. From the identified problems of both groups, 22 specific recommendations for action were derived (e.g., splitting teaching/learning content into two or more modules, revising the course structure, consistency of abbreviations), which served as the basis for the second and final revision of the teaching/learning format.

3.2. Conclusion

The iterative procedure described for evaluating and revising the teaching/learning format has shown that even a small number of test subjects can identify a large number of problems in digital teaching/learning formats. In the first evaluation phase, 50 problems were identified by the test persons with a high dispersion of the average reported problems ($\bar{x} = 38.6$; $s = 8.3$). After the first revision, the number of identified problems was reduced in a second evaluation phase conducted by a comparable cohort ($n = 21$) and also the dispersion of the average identified problems decreased disproportionately ($\bar{x} = 16.7$; $s = 2.8$). The comparison of learner evaluation and focus group revealed that ten of the identified problems of both groups were due to the same cause. A summary of the results can be found in figure 5.

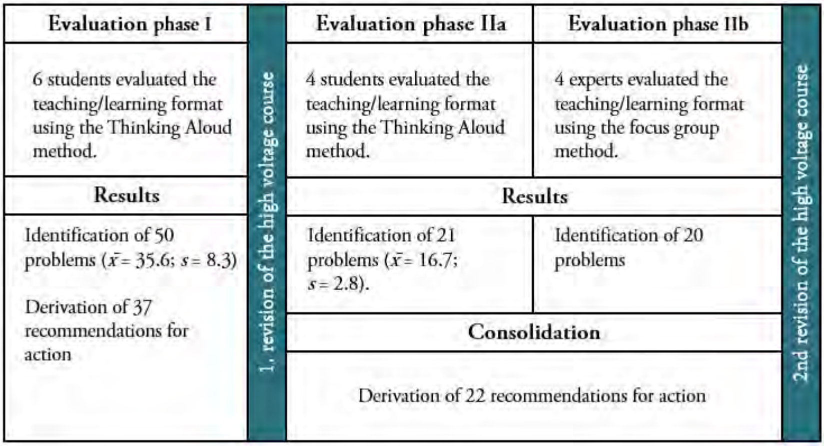

Figure 5: Overview of the number of problems identified
and derived recommendations for action

Furthermore, it was shown that the identified technical problems of all cohorts and the focus groups could be assigned to the usability criteria of DIN ISO 9241-110 (ISO 9241-110: 2020). However, the clear assignment was partially problematic: For example, six of the ten participants of the learner evaluation noted that designations or abbreviations were used inconsistently, which represents a problem of conformity to expectations according to DIN ISO 9241-110 (ISO 9241-110: 2020). However, these problems were partly inherent to the teaching/learning content used, so that a separation between technical and didactical problems was not always clearly possible. However, the analysis not only enabled the digital framework of the teaching/learning format to be revised, but also inconsistencies in the (analog) teaching/learning content and materials to be identified and eliminated.

4. Findings

User-centered development and the usability of software systems have been an integral part of sales and corporate strategies for decades (Donahue 2001). Digital teaching/learning formats in which teaching/learning content is embedded, on the other hand, are rarely subjected to usability testing and placed in the focus of user-centered development. Using the example of the high-voltage awareness course, it was shown that user-centered development with a focus on usability is necessary to enable the process of learning in a digital context to be as free as possible from (technical) disruptive factors and, in addition, to be intuitive and interactive.

In the following, recommendations for action are presented that were derived from the process of creating and evaluating the high-voltage awareness course and can be applied regardless of the topic of the teaching/learning content. The recommendations for action mentioned were extracted from the statements of both learner evaluations and the focus group (see Figure 5).

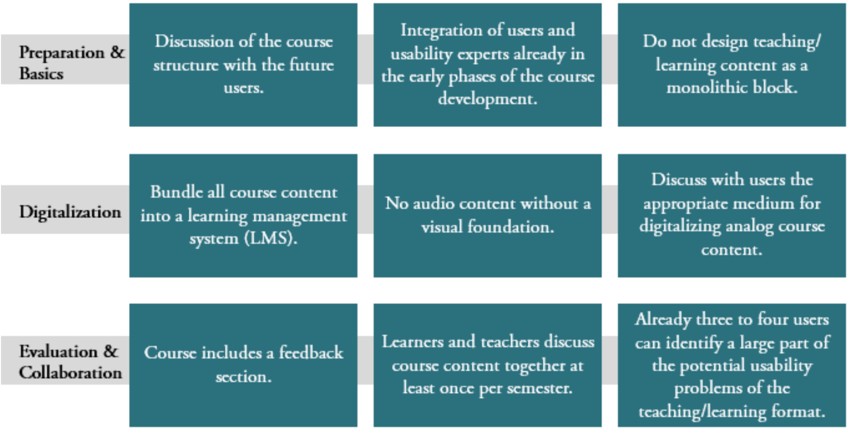

Figure 6: Recommended actions for creating a digital teaching/learning format

5. Limitations

The applied method has various limitations. For example, only passing the course of high-voltage awareness was assumed as a basic requirement for participation in the experiment, but the exact level of knowledge was not checked. This can lead to the fact that course contents were evaluated by test persons depending only on their own level of knowledge or that insufficiently explained contents were not recognized as such by test persons with good knowledge. Furthermore, the test took place under laboratory conditions and each subject was supervised by an experimental supervisor. The presence of the experimental supervisor could limit the ecological validity of the results, as the subjects were constrained in their typical learning process by the observation. Additionally, the learning process could be further limited by using the thinking aloud method, as verbalizing thoughts could make it more difficult to understand and evaluate content.

6. Outlook & preview

The iterative design process described above shows the relevance of developing (digital) teaching/learning formats together with the learners or potential users. The initial prototype of the teaching/learning format was created without involving the learners and contained a large number of technical and content-related problems. However, this article shows that the future users, in this case the learners, should be included early in the didactic development process in order to meet their needs and requirements. By this way, possible technical, content-related or design-related problems can be addressed in advance, thus facilitating the transfer of the content to be conveyed.

By using the method of thinking aloud, it was possible to identify a large number of the problems that arose and their causes in the first evaluation phase with a small number of six test persons. In the second evaluation phase, the number of identified problems decreased significantly, even though the teaching/learning format was evaluated both by the learners and by a focus group consisting of experts from the fields of usability and education. This suggests that the integration of learners and teachers should take place early in the development process in order to make digital teaching/learning formats as intuitive to use as possible and thus support the learning process. In addition, this participatory process creates further advantages: Existing teaching/learning content can be checked in parallel for content-related problems, its structure can be scrutinized and optimized, and learners have the opportunity to actively influence the process of teaching/learning. Ideally, learners not only become consumers of knowledge, but can also help drive the digital transformation in education and training.

The identified technical problems in all evaluation phases could be assigned to the usability criteria of DIN ISO 9241-110 (ISO 9241-110: 2020). However, it has been shown that it is not always possible to clearly separate content-related problems that affect the teaching/learning content from technical problems. In some cases, content-related and technical problems are mutually dependent or potentiated. Furthermore, there is currently no evaluation method that combines usability and content evaluation of digital teaching/learning formats. As a rule, these evaluations are carried out separately from each other, which makes it difficult to identify common problems as well as common potentials. Therefore, the goal is the conception of a hybrid combination of usability and evaluation methods in order to be able to capture synergy effects in a structured way.

Furthermore, the user-centered method for the creation and evaluation of digital teaching/learning formats outlined in this paper is to be iteratively further developed and used in other educational institutions in the field of training and further education. The goal is the development of a generic procedure that makes it possible to create learning formats that optimally support and promote the learning process, taking into account the needs and requirements of learners and teachers.

Acknowledgements

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Transdisciplinary competence development for role models in data-driven value creation

The Citizen Data Scientist in the Centre of Industrial Data Science Teams

Jochen Deuse, René Wöstmann, Lukas Schulte, Thorben Panusch, Josef Kimberger

Increasing digitalisation is fundamentally changing the understanding and possibilities of value creation as well as labour organisation. The systematic collection, storage and analysis of data is becoming a decisive competitive factor and is the basis for intelligent products, processes and production technology. This results in new competence requirements and roles in mechanical and plant engineering and in the manufacturing industry in general. Machine Learning (ML) in particular, as the basis of Artificial Intelligence (AI), poses great challenges for companies, as the demand for experts, so-called Data Scientists, significantly exceeds the offer and 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 (CDS) as a link between the most important disciplines of information technology (IT), domain knowledge and data science enters the focus of attention (Idoine/Brethenoux 2019). The article presents a role model as a basis for team building and systematic development of ML competences in the manufacturing industry and combines the results of various research projects and industrial implementations. For this purpose, required ML competences of the future are derived in section 1 and transferred into a transdisciplinary role model in section 2. Section 3 addresses the exemplary practical application in an industrial use case, while section 4 gives an outlook on the possibilities of target-oriented competence development for the individual roles and actors.

1. Machine Learning Competences of the Future

Increasing digitalisation and the spread of information and communication technologies (ICT) enable the systematic collection and storage of data. The systematic data analysis becomes a decisive competitive advantage through its use for optimisation and decision-making processes (Eickelmann et al. 2015; Wölfl et al. 2019). In particular, the use of ML enables the discovery of unknown and non-trivial structures and relationships and results in new perspectives of providing knowledge (Dragicevic et al. 2020). As an overarching discipline between com-

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puter science and statistics, it empowers data-driven insights, decisions and automated data processing. However, data analysis becomes a decisive success factor for companies when combined with domain-specific knowledge (Deuse et al. 2014). As a result, there are competence requirements with regard to a profound methodological understanding in the field of ML as well as a distinct technical understanding of engineering problems in order to meet the challenges of industrial companies in a demand-oriented manner (Bauer et al. 2018). Therefore, interdisciplinary teams from the three disciplines of computer science, statistics and engineering have to be formed on the company side. However, a lack of resources - especially for small and medium enterprises (SME) - limits the formation of such teams (Rammer et al. 2010). In particular, these companies have a strong domain knowledge of their own processes, but not in implementing ML in production (Bertelsmann Stiftung 2018; Morik et al. 2010). Therefore, the CDS is gaining importance: this role, first introduced by Gartner, describes a domain expert who is capable of using ML in the data-driven decision-making process, but whose job function is outside statistics and computer science (Moore 2017). This role is becoming important as the availability of ML tools is increasing exponentially, but the rate of Data Scientists is not increasing at the same level (Miller/Hughes 2017; Mullarkey et al. 2019). Due to this, the potential of data analysis is not fully exploited, creating an economic disadvantage (Mazarov et al. 2019). In this context competences describe knowledge and skills that are acquired through teaching and learning processes (Fölsch 2010) and can be used by individuals in a targeted manner to successfully solve problems in different situations (Weinert 2001). Thus, in manufacturing industry, competences can only be developed through the concrete and problem-oriented application of knowledge and skills (North et al. 2016).

1.1. Derivation of general ML Competences within the Industry

In order to enable problem-oriented competence development, the relevant competences have to be identified. For this purpose, (Bauer et al. 2018) interviewed companies from various industrial sectors such as automotive, electronics and mechanical engineering regarding the degree of use of ML in industrial practice. Only 5 out of 57 companies (9 %) are successfully using ML in industrial practice, while 27 companies (47 %) are using ML to a small extent or piloting initial applications. The remaining 25 companies (44 %) plan to use ML in the future without using it yet. To identify the obstacles of integrating ML into industrial practice, the companies were surveyed in more detail. The main obstacle of using ML is the lack of methodological competences. Furthermore, the increasing complexity of manufacturing processes leads to an increase of required professional competences. Another major challenge is the transfer of the acquired theoretical knowledge to the practical issues and areas of application. In the survey, the companies indicate a high importance for the competence categories of ML, ICT and domain knowledge, but also social and personal competences. (Schulte et al. 2020).

Based on these findings (Bauer et al. 2018) derive an approach to enable ML in industrial production by developing the tripartite Industrial Data Science (InDaS) model (Fig 1) as the basis for a transdisciplinary course of the same name at TU Dortmund University as part of the research project InDaS

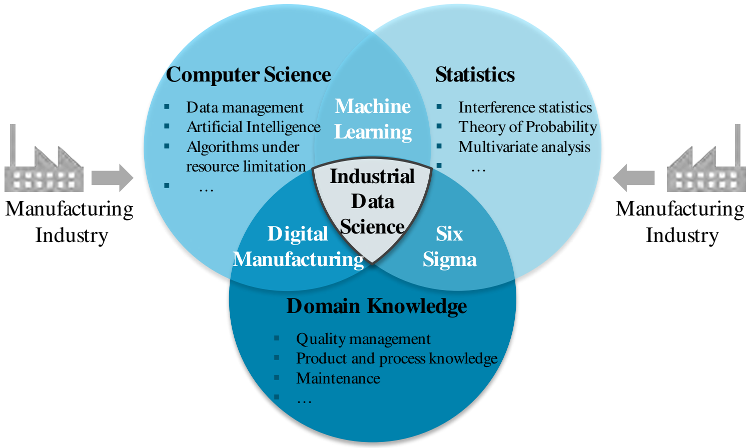

Figure 1: Industrial Data Science as a transdisciplinary approach (Bauer et al. 2018; Schulte et al. 2020)

1.2. Detailing transdisciplinary Categories and Competences

The InDaS model (Fig 1) addresses a transdisciplinary approach to solving challenges with ML in an industrial context. It provides a first suitable overview of disciplines and expertise to be integrated and addresses esp. professional competences. However, a deeper level of detail is required. Within the research project ML2KMU, (Reckelkamm/Deuse 2021) work out that in addition to the professional competences also methodological, social and self-competence play a decisive role. In the following, the individual categories are presented in more detail. Based on the InDaS model and the literature research listed by (Reckelkamm/Deuse 2021), domain knowledge and competences in the categories of ML, statistics, data management and ICT are emphasised as professional competences. The domain knowledge addresses e.g. knowledge about manufacturing processes, the ability to identify ML potentials, to assess framework conditions and possibilities for inference in deployment. The ML competences consist of knowledge of ML methods and models, programming languages and software tools, feature engineering and selection, the creation of visualisations, validation and performance metrics as well as operationalisation of models in deployment. The competences in the area of statistics address application oriented skills in descriptive statistics (e.g. metrics, visualisation forms), multivariate statistical methods, theory of probability and time series. The competences in data management include database technologies, cloud solutions, IT systems and structures as well as mechanisms for privacy and security concerns in industry. The ICT competences address on the one hand the mastery of automation technology (e.g. human machine interfaces (HMI), programmable logical controllers (PLC) as well as field level interfaces and protocols), sensor technology, Industrial Ethernet, shop floor IT systems such as manufacturing execution systems (MES) and machine data acquisition (MDA), but also Edge Computing, which plays an increasingly important role in ML for distributed decentralised data collection and execution of models. Methodological competences include skills and application of Lean Management methods for conventional process optimisation, as well as knowledge of how to perform data-based improvements such as the DMAIC (Define Measure, Analyse, Improve, Control) process model of the Six Sigma philosophy. Knowledge of ML related models such as the CRISP-DM (Cross-Industry Standard Process for Data Mining) of KDD (Knowledge Discovery in Databases) is required to structure projects. In general, methodological skills also include presentation techniques, operational project management as well as special methods such as Design Thinking or agile frameworks like SCRUM, some of which, however, can also be seen as optional depending on the specific tasks and teams. The social competences address the ability to work in teams, communication skills, conflict management, leadership, cooperation and empathy. In addition, self-competence is required, which addresses characteristics such as the willingness to learn, adaptability, curiosity and openness as well as creativity. Figure 2 summarises the categories of competences. It becomes clear that ML is a transdisciplinary cooperation of different professional domains and actors and therefore addresses heterogeneous competences. Many of the existing approaches address only the professional competences, which, however, does not provide a complete picture, especially for application-driven data science, such as the rise of CDS. In the following section, specific role models will be presented in order to be able to assemble and develop teams in a targeted manner.

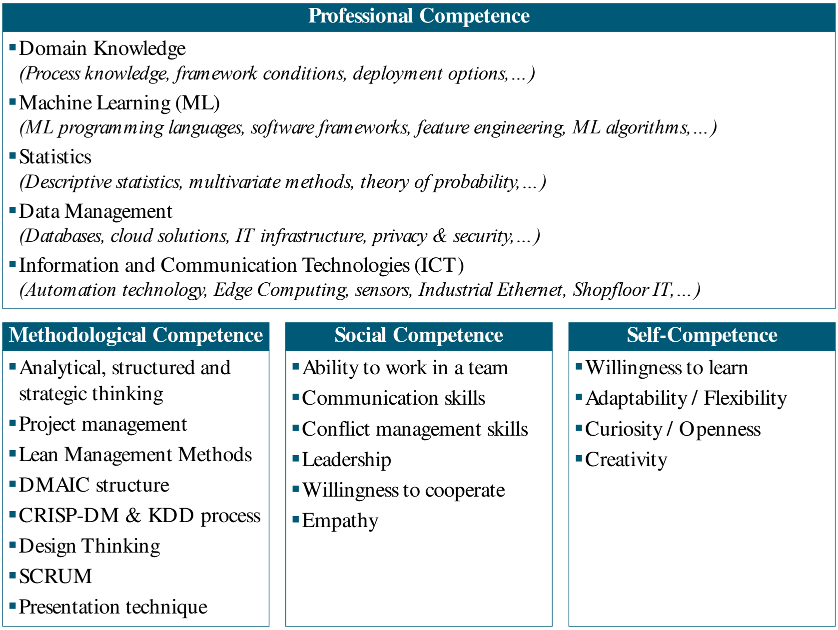

Figure 2: Categories of competences required for ML projects in manufacturing industry

2. The Citizen Data Scientist in the Centre of Industrial Data Science Teams

Although the competences identified are useful for a general overview of the disciplines to be represented in implementation projects or the organisation, for a detailed team composition not only the competences but also the roles and actors need to be specified in more detail. The literature contains both theoretical models for the general composition of ML teams, e.g. (Saltz/Grady, 2017) and practice-oriented guidelines, e.g. (RapidMiner 2020). However, previous approaches are either too specific in detail or too generically and only partially address the domain of the manufacturing industry. In addition, none of the existing work adequately addresses competence development in an integrated role model. Therefore within the research project DaPro (Data-driven process optimisation based on machine learning in the beverage industry) (Wöstmann et al. 2019), transdisciplinary role models were defined based on the preliminary work of the InDaS project and the DPDA (Data Preparation for Data Analytics) project group (Stark et al. 2019) of the prostep ivip association and a practical application context was created for validation. An overview of the role model is shown in Figure 3. It consists of the roles of IT, Domain Expert, Data Scientist and Management, whose particular areas of expertise are integrated by the CDS in a central orchestrating role.

The basis for both the delimitation of the roles and the design of the competence profiles is formed by iterative workshops both in the prostep Group DPDA and within the DaPro project with practitioners from manufacturing industry, mechanical engineering companies, Data Scientists, IT companies and research institutes. The disciplines of the competences were expressed with different competence levels. The levels consist of no competence present or required (0), basic information present (1), which becomes knowledge (2) through application and interconnection. This is extended through willingness and practical experience to competence (3). Furthermore, the highest level (4) addresses the ability to synthesise and evaluate different approaches and disciplines. The gradations are thus based on the knowledge steps according to (North et al. 2016) as well as the stages taxonomy model according to (Bloom/Engelhart 1976). The partially odd values of the competence levels in the following section result from the process of individually interviewed industry and research experts from the InDas, DaPro, AKKORD, DPDA and ML2KMU projects and subsequently combining the ratings in order to obtain a more valid overall view. For aggregation, the mean values of the assessments of the interviewed experts were used. In the following section, the individual roles, their specific tasks and responsibilities as well as the underlying competence profiles are presented.

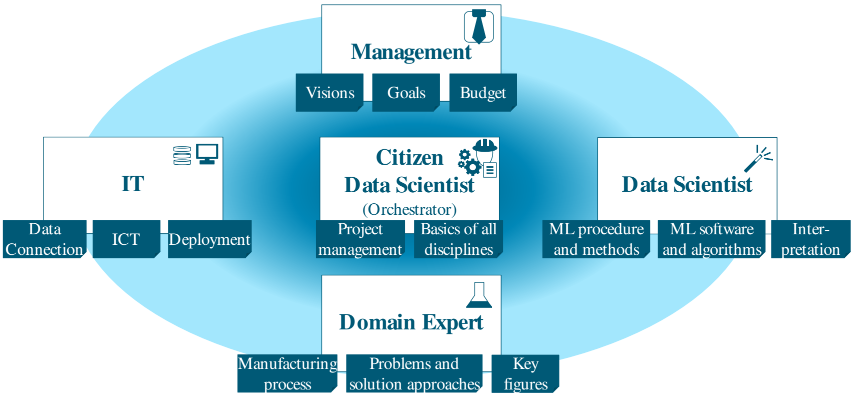

Figure 3: The Citizen Data Scientist in the Centre of Industrial Data Science Teams

2.1. Management

Fundamentally, Management has an important role to contribute. Without the active involvement, initiative or support of the management, there will be no sustainable success for any ML-driven initiative in manufacturing companies. The tasks consist of constituting a common vision and initiating projects. The composition of the project team and the provision of resources (e.g. budget and working time) play an important role. In addition, Management can help to open doors by encouraging internal cross-departmental communication, but also by engaging external partners. During the project, Management takes on a more passive role, advising the project team as required, assisting in escalations and mediation of conflicts, making decisions at important points and being informed about the progress through reporting and controlling. Even if new agile approaches such as SCRUM are chosen for operational implementation, the Management must enable the organisational conditions for this. In addition, it is both strategically responsible for the integration of ML projects into the corporate strategy and operationally involved in their implementation. The requirements for the role of Management are also reflected in the competence profile (Figure 4). A high level of self- and methodological competence is required to equip the teams with the relevant tools and to inspire enthusiasm for general visions and specific ML-driven initiatives. In addition, social competence helps in assembling the right teams and resolving conflicts. Less necessary in Management are technical competences, which are covered by the other roles. Domain knowledge should be emphasised, as it is a fundamental factor in assessing the practical applicability and relevance of the analysis results.

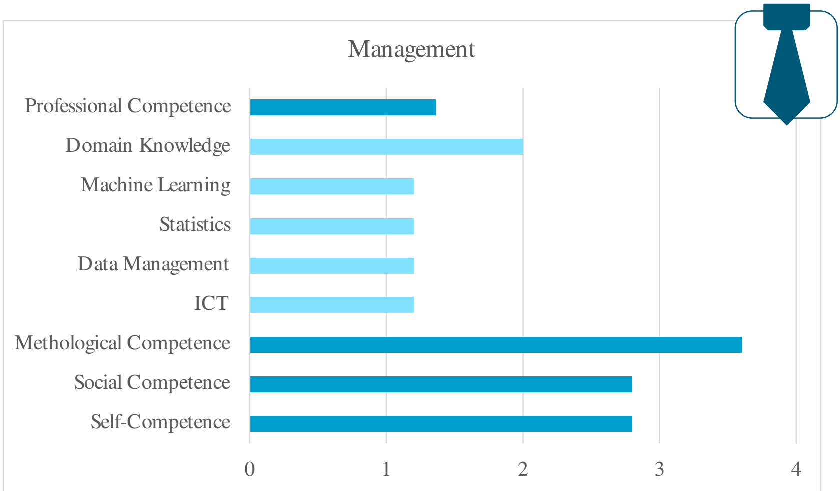

Figure 4: Competence profile of the Management role

2.2. IT

The role of IT is fundamental to the data-driven application of ML. Firstly, it provides insights into the possibilities and restrictions of productive IT systems regarding e.g. accessing data sources. Furthermore, it helps in the consideration of legal concerns such as privacy and security. The IT role should have a comprehensive overview of suitable ICT (e.g. database technologies, IoT protocols, edge devices and platforms). It plays a fundamental role in the implementation of architectures for ML. In smaller companies and one-off projects, this can be rather simple, including hosting servers and making data access available, installing analytics software and providing deployment options. In more advanced projects with a higher degree of complexity, where, for example, larger amounts of data are processed and greater computational power is required, IT sets up and maintains platform solutions and distributed computing and storage services, or enables the use of commercial Platform-, Infrastructure- or Software-as-a-Service (PaaS, IaaS, SaaS) solutions. Furthermore, services and the operation of an own platform ecosystem are becoming increasingly important for machine manufacturers. The role of IT is therefore to be considered heterogeneous and can be partially differentiated into further sub-roles, e.g. data engineers, solution architects, or platform teams. The most important competence requirements (Figure 5) are specific technical competences like ICT skills and data management. A basic ML knowledge helps to understand the requirements for architectures both for testing and training, but also for deployment, and to be able to translate them into implementations. A basic knowledge of the application domain also contributes to this.

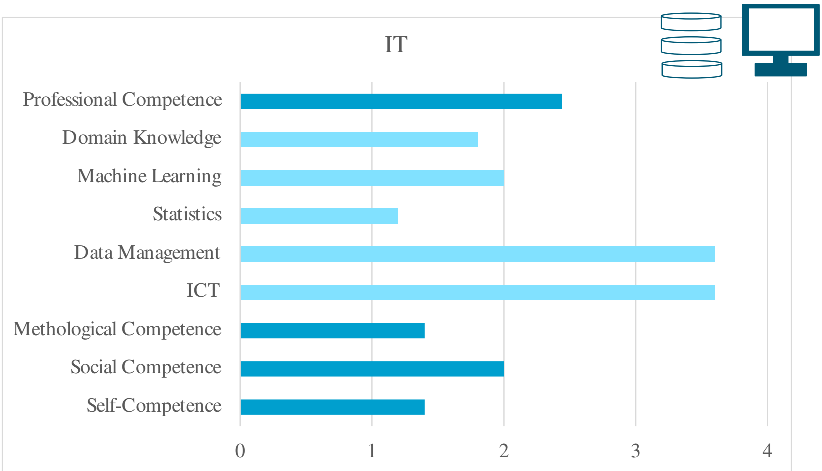

Figure 5: Competence profile of the IT role

2.3. Domain Expert

Domain Experts play a central role in ML implementation projects in the manufacturing industry, as they contribute the most profound knowledge about value adding manufacturing processes. They can represent the starting point of a project and identify needs in real application scenarios. In the interdisciplinary teams, they explain the problems to the other actors involved and play an important role in the brainstorming of solutions, since they are able to assess both the possibilities and the restrictions of the real processes in the most valid way. In this context, their task is also to define requirements for the solutions to be developed. Furthermore, the definition of performance and result indicators plays an important role, which can be used to quantify both problems and improvements. Domain Experts know the IT systems from a user's perspective and can define the conditions for deployment options. They also help in evaluating and validating model outputs in terms of transferability and applicability to real processes. With regard to the competence profile (Figure 6), conditions of self, social and methodological competence are comparable to those in IT and indeed useful qualities for the daily work. In ML implementation projects, however, these do not necessarily have to be fully developed, as the project management tasks are performed by the orchestrating role. Therefore, professional competence is of highest importance. On the one hand, a basic ICT knowledge cannot cause any disadvantage in order to be able to comprehend the IT systems, underlying data as well as possible deployment scenarios. However, the key competence of Domain Experts is domain knowledge that includes process knowledge as well as general ML and deployment potentials.

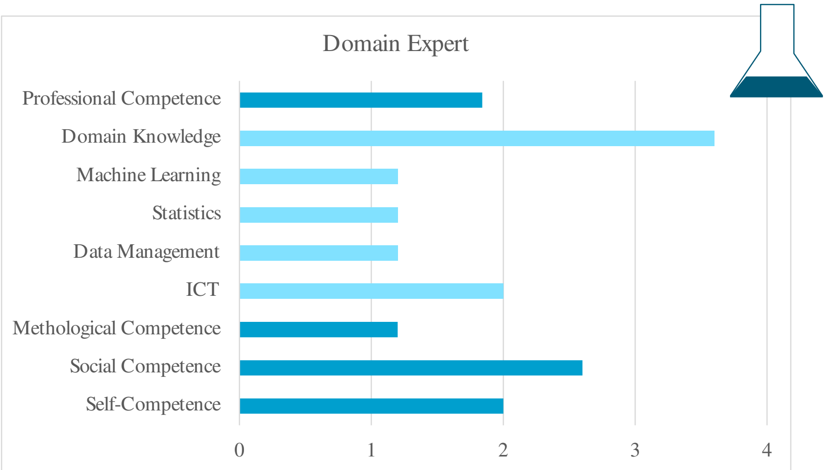

Figure 6: Competence profile of the Domain Expert role

2.4. Data Scientist

To enable ML-based analysis, the role of the Data Scientist aims to integrate ML and AI related know-how. Fundamentally, the role brings structuring options and process models for ML projects. Initially, an essential task is to enable the assessment of data availability and quality from an ML-oriented perspective. The goal in this context is to translate visions and ideas into realistic expectations. Furthermore, it helps in the selection of software for the ML environments. The content-related Data Science tasks such as feature engineering, explorative analyses as well as training and validation of models are carried out by this role. Permanent coordination with the Domain Experts is important in order to ensure the feasibility and practicality of the analyses, to increase the quality of solutions and to create acceptance for later deployments. Furthermore, the Data Scientist plays a major role in the design of the deployment environment, which addresses the operationalisation of models. In particular, the transfer of analysis processes into scoring processes must be carried out by the data scientist in close coordination with IT and Domain Experts. The competence profile (Figure 7) addresses basic methodological competences to enable a structured implementation of ML projects. Since much of the implementation depends on the Data Scientist, self and social competences are also required. The core tasks, however, consist of technical competences in ML like programming languages, learning strategies and software tools. Furthermore, a Data Scientist must have high competences in the areas of ICT, data management and statistics in order to build up an adequate data connection management and to be able to represent the ability of model interpretation.

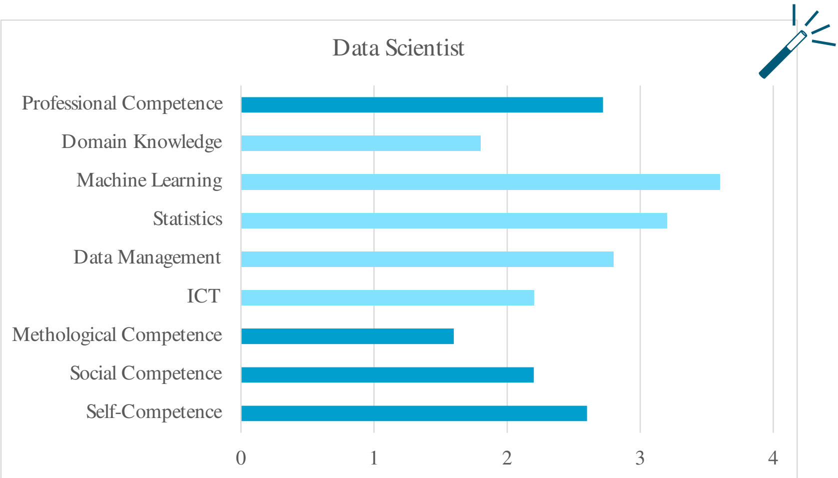

Figure 7: Competence profile of the Data Scientist role

2.5. Citizen Data Scientist

As a coordinating role between the specific roles of the Domain Expert, IT and Data Scientist as well as the Management, an integrating position of the operational project management is required. This orchestrating role of the CDS is responsible for typical project management tasks such as organising deadlines, scheduling and stakeholder management. It leads the analysis of the current situation and the collection of requirements in the early project phases of business and data understanding. The CDS plays an important role by translating real problems into ML problems. During the technical work, it moderates between the various actors, contributes to the decision-making process and reports on the progress of the project to the Management. In the course of an ML implementation project, it has to assess various ML relevant contents, such as IT systems, data quality, software and model selection, evaluation criteria, performance metrics, etc. All of this leads to a new job description of CDS, since numerous Data Science related skills must also be developed to an action-oriented degree in this role. The competence profile of the CDS role (Figure 8) reflects the requirements of the heterogeneous tasks. Thus, the central orchestrating role has to meet the most diverse competence requirements. As the central contact for the project, he or she must have the highest level of self-social and methodological competence. This includes team building and motivational skills as well as organisational talent, analytical, structured and strategic thinking, flexibility, openness and willingness to adapt. In addition, the Citizen Data Scientist needs high hands-on competences in ML and esp. domain knowledge and thereby creates acceptance of models and deployments.

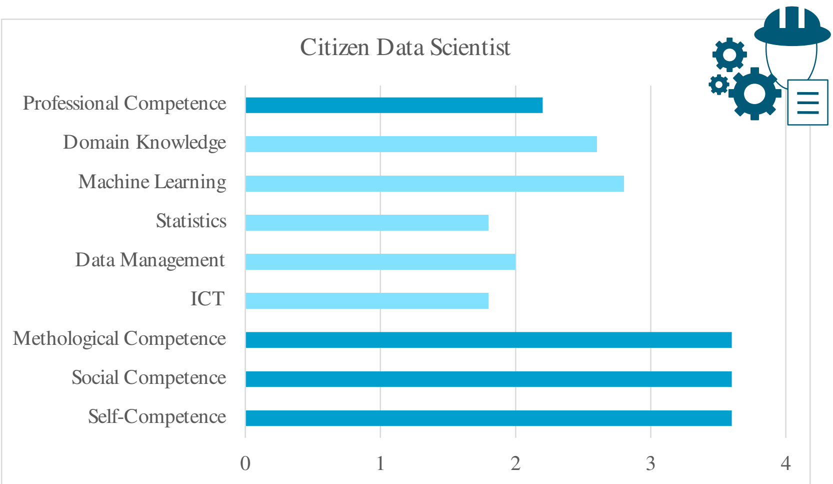

Figure 8: Competence profile of the Citizen Data Scientist role

3. Case Study in the Beverage Industry

The role model shows a conceptual structuring of actors in ML projects in manufacturing industry, which is to be specified individually for each initiative. For demonstration and validation, the following section shows an implementation example. For this purpose, interdisciplinary teams consisting of Domain Experts, IT, Data Scientists and Management were formed for each use case scenario in the DaPro project, which were orchestrated by a Citizen Data Scientist within a case study on the use of ML to optimise malt yield at the Bitburger Braugruppe (Wöstmann et al. 2020).

3.1. General Matching of the Role Model and Project Organisation

In general, ML and AI methods needs to be part of the digitalization strategy of a company to have any chance for success. The mission for implementing data science has to be communicated from top down by the Management role to get the support from all stakeholders in a brewery. Failing in this basic requirement will delay a serious implementation and will result, if at all, in isolated solutions. Nevertheless, isolated solutions might also be the vital spark of interest for a more general approach.

An ideal proof of concept was to implement ML in a highly automated industry such as a large scale brewery as Bitburger Braugruppe. Having only minor experience in explorative data analytics such as methods like Six Sigma, implementation goes along with defining role models inside an already implemented project management system, based on the PRINCE2 project management method (AXELOS 2018). Working on a ML-based use case has many parallels to a standardized project cycle, adding specific steps of the CRISP-DM model to the project definition and the execution stage. In a regular managed project, there are roles defined such as a Steering Committee including members of supplier and customer representatives which monitor the definition and the result of a project. Experts on demand give general support with interfaces to all stakeholders and departments. A Project Manager to set up a project plan and sets milestones for the unique project steps. The Manager reports to the steering committee. And finally, an analysis and implementation team, which is responsible to complete the defined tasks. Depending on the complexity of the given project topic, the project itself can have multiple subprojects with different focuses. In this case there will be a responsible Project Manager for every subproject, but one Coordinating Manager above for orchestration. Optionally there is the possibility to include a coach for different tasks such as key lessons on new methods, consultation on best practices and in the worst case for de-escalation. In ML-based use cases the relevant departments or stakeholders, included in a project have been clearly defined (Figure 3). In the beginning it is necessary to map the roles of these stakeholders to positions and departments in breweries. Having also developed a brewery specific reference architecture (Figure 9) within the research project DaPro for developing ML-based use cases it is necessary to map the interface partners, which are actively involved in the use case, to key elements of the ML architecture. (Wöstmann et al. 2020).

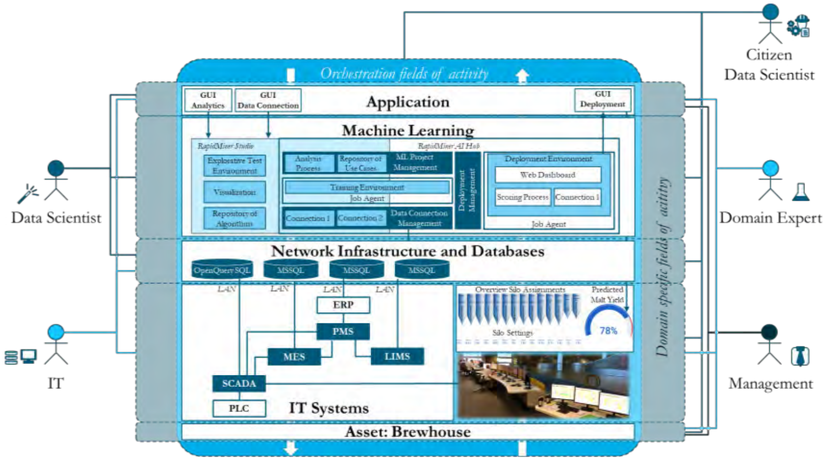

Figure 9: Key Fields of Activity of involved Roles in a Use Case-specific ML Architecture

The key project handler in data science projects is the CDS. In Breweries this position is responsible to set up the project management and has to be acquainted the basics of the production processes, quality assurance, database and IT architectures as well as ML methods and advanced statistics. Having all this know how combined, he is the most valuable team member of working on data science use case. The transdisciplinarity of this position requires an open minded engineer, either as a Domain Expert or from the Data Scientist area to deeply dive into the respective other discipline. The CDS has to identify possible use cases, get the necessary stakeholders (Domain Experts, IT) into the project team, and also reports the milestone results to both management and the customer representatives.

The role “Experts on Demand” of PRINCE2 is analogue to the Domain Experts in this proposed role model. The term “domain” is always referred to the focus of the respective department of the company where a use case is being implemented. Domain experts give the CDS the required information regarding the processes and the scope and boundaries of the use case itself. Respective to the DaPro project team members of the Domain Expert team should combine all aspects of production interests. E.g. a production manager should always consider quality aspects, thus a quality expert should be on the team as well. If the desired prediction results in changing downstream processes an expert of downstream departments might need to be consulted. The interface between production and the supply chain management is bottling and logistics.

Another kind of expertise is the participation of the IT department. In a classical project management approach, the IT is part of the project team or an “Expert on Demand”. During a ML project the IT is a vital partner, as the ML architecture has to be hosted, maintained and monitored. When implementing the first ML use case the first step is to manage the connectivity to all necessary data sources and a first introduction to the database schemas and its tables and its content. As a preferred conceptual focus, the IT role in breweries has both a dedicated technical IT focused on production and quality and a general IT for network administration. The IT supports the CDS in setting up a data science platform and provides the resources for hosting computationally intensive analytics processes. The IT has also a major responsibility for deploying process into production.

Depending on the progress of ML implementation breweries may have more than one Data Scientist employed and integrated in the brewery's organization. Data Scientists in breweries however are a luxurious asset, since their focus is more generalized, and they do not have much experience in domain processes. Data Scientist however have the general background of data analysis, its explorative approach, deep understanding of algorithms and modeling and also the ability to understand and interpret the model results. This asset may therefore be also part of the tasks of a CDS if a general Data Scientist is not at hand in the respective brewery's organization.

3.2. Exemplary industrial application scenario of malt yield prediction

Having described the individual specifications of the roles within a brewery, a use case to predict the malt yield in the brewhouse is used to validate this model. The malt yield is an important key figure to measure how much extract, has been extracted from the raw material malt depending on the produced quantity of wort and the total amount of malt used in the brewing process. Predicting of this key figure gives brewmasters enhanced possibilities to react in the automation of the processes and a choice in selecting the right ratio of raw materials. The earlier a brewmaster has prediction assistance the better will be the possibility to react.

A brewmaster in this use case has two roles, both being the Domain Expert and on the other hand the contracting entity with the initial idea and definition of the problem. Along the project cycle the Domain Expert has to give advice and evaluate anomalies found in the data for further interpretation. The use case has three major data sources for evaluating processes and raw materials. First being the supply and storage of raw materials, secondly the production processes itself with input and output parameters and thirdly the quality control of both product and raw materials. For this the Data Scientist or CDS is relying on data from SCADA (Sequence Control and Data Acquisition), LIMS (Laboratory Information Management System) and PMS (Production Management System) systems (Figure 9). Brushing against points of contact in quality assurance, the quality department can also give valuable input. In an initial phase of data understanding the Domain Experts (quality and production) help to understand which data is being collected and what the data means for employees outside the domain. A significant issue is the timestamp when a data point is being measured and appended to a data point list.

Shortly explained the time offset of a datapoint to a process is substantial to whether include this feature in a model or not.

It is important to note that most Domain Experts work with specialized reporting systems and seldom have information where the date is being stored and how the raw data looks like. At this point it is necessary to include the IT in the use case. The best-case scenario is to have an IT expert at hand who has a good inside how the backend of reporting systems look like to get fast access to raw data and support for basic modelling in the data preparation phase of the cycle. The data understanding and preparation phase is a constant circuit to help the Data Scientist or the CDS setting up a data pipeline and analyse which data becomes crucial for the prediction model.

The goal for this use case was to get the prediction feedback to the start of the process, meaning that when a production batch is started the result needs to be clear beforehand. The result of the data understanding phase was to shift the analysing focus on a complex silo management to develop a tracking system which malt deliveries ends up in a batch, paired with malt specifications of the incoming inspection. Bitburger uses 14 different silos, all reserved to a different supplier, generating a complex composition and mapping of deliveries. Having solved the silo black box on an abstract level, a large part of the complexity of this use case was removed, enabling training a model on historical data and providing first predictions. For predictions several algorithms were used, with Random Forest and Gradient Boosted Trees performing best in accuracy and error giving the brewmaster results within the measurement inaccuracy of the automation sensors and laboratory analysis.

ML models always have their own cross-validation included to measure prediction performance. However, these "raw" first predictions also need to be validated in a production environment. Here the Domain Experts play a significant role to check on the results itself. In collaboration with Domain Experts and Data Scientist a validation concept needs to be developed, setting up a prototype deployment in production and feeding the model with live production data. The IT department may have to be included on how to implement a deployment for the domain departments. The validation concept has to be evaluated on a regular basis to improve handling and the prediction results if necessary.

The management of a department or the brewery director needs to be informed of the progress and the results recurrently. Management always needs to assess the costs and risks of a use case and weigh up the benefit for the department or brewery since asset and personnel resources are bound during development and deployment. Moreover, the Management is responsible to mediate between departments and special interests. In this special use case interests of production planning and procurement are necessary to be informed in a future deployment strategy.

The CDS is the orchestrator to integrate all stakeholders in the use case. Depending on the progress the result may lead to a paradigm shift to reappraise procurement or planning processes in general, but this is a distant scope of the use case.

This use case is a significant part of proofing how a properly set up role model can help for introducing data science to a domain like breweries. Having implemented this use case several steps had to be solved along the project cycle. Beside finding and defining the use case itself it was also necessary to set up a ML-architecture (Figure 9), find all necessary data sources, built up a data pipeline for data understanding and preparation which was presented in more detail in (Wöstmann et al. 2020). Enhancing a reliable standardized project management method to ML-based use cases has helped to find the common thread for both data science and ordinary project management. Having developed several tools inside the project to enable non-data scientist to do basic modelling themselves the learning curve since introduction has been steep. Furthermore, a group of students was integrated in order to enable the development of practical competences by combining academic lectures with real InDaS challenges.

4. Outlook: Development of Citizen Data Science Competences

After considering the competences required for ML in the manufacturing industry and differentiating them into roles, the question arises how exactly the development of competences can take place, especially in a job-related perspective. Especially for SME there is a lack of practice-oriented ML competence development concepts, e.g. assistance in choosing training offers. Therefore, it is necessary to develop methodological support that allows the derivation of individual competence profiles and corresponding individual competence development activities. Based on the competence categories presented in section 1 and the role model presented in sections 2 and 3, a platform for ML competence development is to be created in the ML2KMU research project (Reckelkamm/Deuse 2021). The core component is a matching mechanism on basis of the role model for the target oriented derivation of competence development actions. For this purpose, it is required to evaluate existing competences of the respective employees for the designated roles. This evaluation could be conducted, for example, employing an assessment test, a self-assessment, or an external assessment. The assessment results could then be used to determine the competences that are not sufficiently fulfilled for the corresponding role in terms of a target-performance comparison. These competences, which do not fulfil the minimum requirements, can then be addressed individually with target-oriented and practical training programs. The recommendation and provision should be carried out automatically by the platform.

There are various formats for training programs, that mostly are offered online as e-learning courses, or partially as on-site events (Zschech et al. 2018). Online learning platforms esp. address massive open online courses (MOOC) such as Udemy, Udacity, edX, Coursera, and Pluralsight. Also more ML-specific platforms such as DataCamp and Big Data University exist. In addition, large tech companies, including Amazon Web Services, Microsoft, Google, SAP or Cloudera as well as Data Science Platforms like RapidMiner, now offer their own training series customized to their own software. There are also larger academic institutions that offer corresponding ML courses and programs, such as the TU Dortmund University (e.g. the InDaS lecture), the TDWI Academy, the BITKOM Academy, the Data Science Academy in Karlsruhe, the Ludwig Maximilian University in Munich, the Westphalian Wilhelms University in Münster or the Zurich University of Applied Sciences (Zschech et al. 2018). All these courses, however, have in common that they are theoretical in nature and attempt to teach ML in a general way. Building up competences, however, requires experience and a context of practice as well as an industrial context for manufacturing related demands.

For this reason, the Institute of Production Systems, together with the RIF Institute in Dortmund, is developing a joint demonstrator for CDS (Figure 10), to enable students developing applicable oriented competences in the context of the InDaS course and to facilitate a transfer to industry in the context of the ML2KMU project in a strategy workshop concept. The demonstrator consists of a Cyber-Physical micro-brewery with industrial control technology, in which data-driven optimization of recipes is implemented by using ML. Thus, for example, regression analyses can be applied based on resource and process data as influencing parameters. Furthermore, it is also intended to gain a general understanding of complex patterns and relationships of cause and effect in brewing. Using the approachable example of brewing processes, the demonstrator acts as a test environment for the Industrial Internet of Things, ICT and is an ideal way to provide practical experience in the field of ML, whether for students or employees in the industry. Thereby, data flows from the PLC, Edge Devices and sensor technology via pre-processing steps to the Data Science Platform of RapidMiner are to be made transparent and tangible. For companies, this will be provided through the strategy workshops mentioned above, which offers another opportunity of developing ML competences. The employees can step into the individual roles themselves and in this way carry out a practical Data Science project exemplarily. This is to demonstrate and emphasize the relevance of the corresponding ML competences and roles. Besides developing fundamental ML competences, this should be an opportunity to derive strategies for future ML approaches in the own products and processes. These practical impressions should serve as a catalyst for future business models and a deeper use of ML methods at the participating companies.

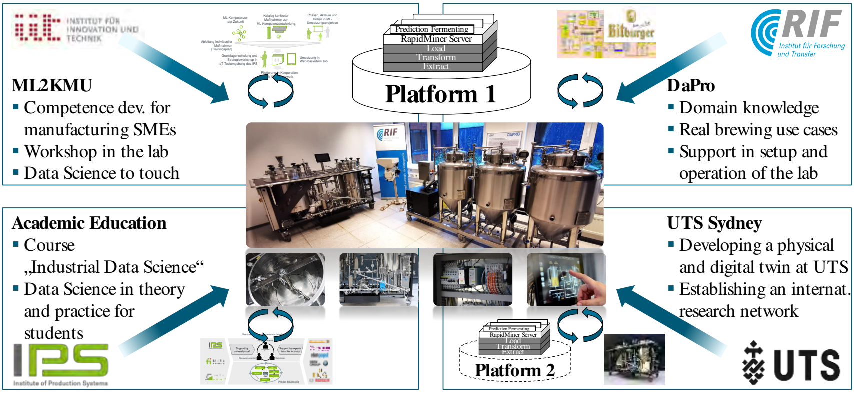

Figure 10: Interdisciplinary Citizen Data Science Demonstrator in Cyber-Physical Brewing Lab

The transdisciplinary work will continue to be expanded in the future through an international exchange with the University of Technology Sydney (UTS). In this context, a physic and digital twin of the brewing demonstrator will be set up in collaboration with UTS. Furthermore, the fundamentally important discussion must be conducted further in detail about which roles are to be mapped internally and externally in the area of conflict between (short-term) economic efficiency and flexibility as well as long-term digital sovereignty. In the vast majority of cases, however, the lack of corresponding competences is not due to an unwillingness on the part of management to support and develop employees accordingly, but to a lack of opportunities to do so in concrete terms. On the one hand, the constant competitive pressure prevents employees from having time to undergo lengthy training courses alongside their day-to-day work. On the other hand, the willingness of employees for further development and to actively demand this must also be created. This results in a growing tendency of outsourcing these activities to external service providers and thus to hand over the future asset of data (Reckelkamm/Deuse 2021). However, the consequent omission of internal development of these competences leads to endangering the company's own digital sovereignty. In other words, the development of these competences is a prerequisite for maintaining the own digital sovereignty and thereby continuing to retain authority over the own data. This is of great significance because digital sovereignty is the key factor for future competitiveness. External dependencies are reduced and self-determination in the digital space is strengthened in terms of autonomous and independent ability to act (BITKOM 2015).

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Virtual Reality Training Applications in Industry

Towards a User-friendly Application Design

Benjamin Knoke, Moritz Quandt, Michael Freitag, Klaus-Dieter Thoben

The purpose of this research is to aggregate and discuss the validity of challenges and design guidelines regarding industrial Virtual Reality (VR) training applications. Although VR has seen significant advancements in the last 20 years, the technology still faces multiple research challenges. The challenges towards industrial VR applications are imposed by a limited technological maturity and the need to achieve industrial stakeholders' technology acceptance. Technology acceptance is closely connected with the consideration of individual user requirements for user interfaces in virtual environments. This paper analyses the current state-of-the-art in industrial VR applications and provides a structured overview of the existing challenges and applicable guidelines for user interface design, such as ISO 9241-110 or Shneiderman's eight "golden rules" for user interface design. The validity of the identified challenges and guidelines is discussed against an industrial training scenario on electrical safety during maintenance tasks.

1 Introduction

Virtual Reality (VR) can be defined as a human-machine interface (HMI) technology that conveys an immersive, interactive, computer-generated experience in which a person perceives a simulated environment in real-time (Mandal 2013). The immersion distinguishes VR from traditional media by substituting the primary sensory input with data received produced by a computer (Heim 1998).

Industrial VR applications are emerging in multiple areas such as education (Salah et al. 2019), telerobotics (Lipton et al. 2017), and production planning (Zhang et al. 2019). Although VR has seen great advancements in the last 20 years, the technology still faces multiple research challenges and holds significant potential (Berg & Vance 2017). The challenges towards industrial VR applications are imposed by a limited maturity of the technology and the need to achieve industrial stakeholders' technology acceptance.

This paper analyses the current state-of-the-art challenges and design guidelines regarding industrial VR applications and discusses the validity of these findings against a VR application on electrical safety training for maintenance tasks. According to the considered VR application, the paper focuses on industrial

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training applications in VR. With regard to the state of the art of VR technology, this paper considers the implementation of the VR application for VR headsets. This head-mounted display (HMD) and the associated controllers for user interaction are tracked with the help of base stations, and the training environment is displayed in the field of view. The user's interaction with virtual objects and the movement through the virtual environment are done by the controllers (see Figure 1).

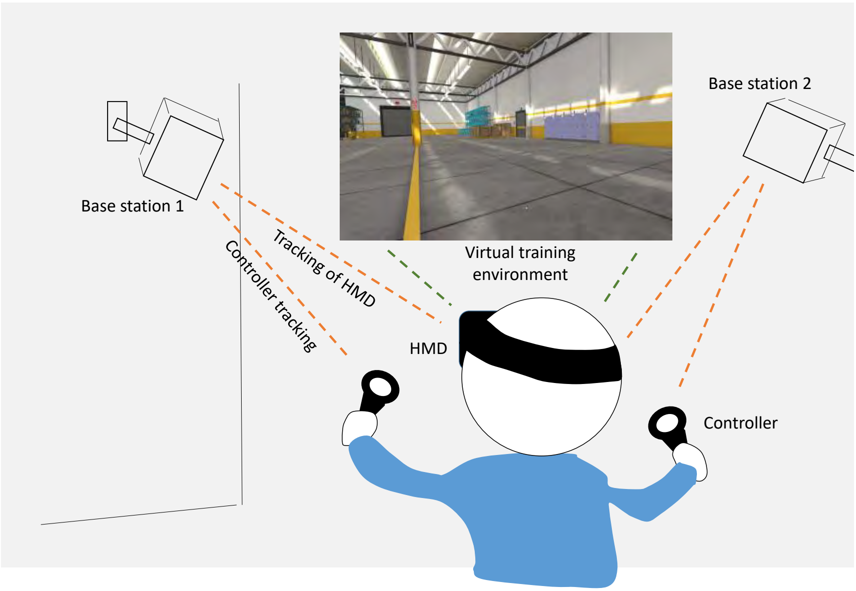

Figure 1: VR training environment

2 Related Work

This section describes related review papers on industrial Virtual Reality (VR) applications focusing on training applications.

Choi et al. (2015) surveyed and analysed 154 papers on VR applications in manufacturing from 1992 onwards. The analysis focused on the application of VR during the development of new products. It showed a significant reduction of costs over time. The authors state that VR technology achieved a return on investment and maturity that enables VR applications to benefit manufacturing companies.

Damiani et al. (2018) analysed 39 papers on industrial Augmented Reality (AR) and VR applications to investigate the current state of the technologies. They state that multiple applications have been successfully tested in real industrial settings and fulfil actual industrial demands. However, only 22% of the identified applications are used for training purposes.

Hasan et al. (2017) reviewed multiple papers on Virtual Reality training applications in maintenance, assembly procedures, welding, and construction training. The authors state that VR training can be used to reduce training costs and could even be used without a trainer.

Patle et al. (2019) reviewed multiple training simulators in the process industry. The author argued that VR has become an integral part of plant operators' modern training and stressed that improved safety, productivity, and environmental protection are the major benefits of VR training.

This research builds upon a systematic literature analysis on simulation-based training in manufacturing, for that 202 applications have been identified (Knoke et al. 2021). The research shows an increase in VR training within the last decade.

A similar paper on the requirements towards industrial AR applications has also been published by the authors of this research (Quandt et al. 2018). While the cost-effectiveness of AR systems is still an issue, operational and administrative issues have moved into the spotlight.

Multiple review papers have been identified. These reviews show that the maturity of industrial VR applications has changed over the decades from a gimmick for technology enthusiasts towards a widely accepted tool with benefits in various areas. However, the maturity of VR technology is still very limited, which impacts the stakeholders' technology acceptance. The authors further elaborate on technical maturity of VR applications in training in the following section.

3 Analysis of Requirements and Challenges

Recommendations towards a user-friendly interface design require knowledge of the current state-of-the-technology and its limitations. Therefore, this paper analyses multiple industrial VR applications regarding statements on technical limitations and challenges. Taking into account the technical limitations of the hardware elaborated in this section, the design of the user interface is a crucial factor in achieving user acceptance. Therefore, the authors elaborate on user interface design guidelines for virtual enviroments in Section 4.

Earlier publications emphasised the quality and cost as a major downside for the acceptance of VR applications (Mujber et al. 2004, Fernandes et al. 2003). Fernandes et al. (2003) also link a low simulation quality to a low immersion and describe the lack of intuitive movement options as a factor that further reduces immersion and training capabilities. In a comprehensive review of VR applications in various contexts, Halarnkar et al. (2012) identified five main challenges for developing and using VR: cost, usability, software limitations, programming capabilities and aspects of interface and design of the applications.

The Kickstarter campaign of the Oculus Rift in 2012 started a hype that resulted in a new wave of commercial interest in VR, causing a significant increase in quality and a decrease in hardware prices (Rose 2018). Now, multiple companies offer commercial VR systems. Current VR HMD systems include:

- Oculus (Quest 2, Rift S)
- Valve Index
- PlayStation VR
- HTC Vive (Pro, Cosmos Elite)
- HP Reverb
- Pimax Vision

More recent publications describe the creation of quality content as the most significant limitation towards a wide distribution of VR training (Büttner et al. 2017, Zhang 2017, Liagkou et al. 2019, Scott et al. 2020). Liagkou et al. (2019) describe the need for a standardised scenario design to reduce the time and cost requirements. Wolfartsberger et al. (2018) stress that CAD models are often available but need to be converted to be used in VR applications.

However, there are still multiple technical limitations that negatively impact the stakeholders' technology acceptance. Wolfartsberger et al. (2018) state that inaccurate collision detection and realistically implementing haptic feedback are significant challenges for interaction with virtual objects. Zhang (2017) argues that any HMD system that requires a user to use artificial devices such as a keyboard or controller to move within the virtual environment can break the immersion. The author also states that HMDs cause motion sickness after longer periods of use, that haptic feedback is mostly unsatisfactory, that interactions with the training simulation are limited by hardware and design, and that any implementation of simulation-based training must consider the individual characteristics of its users. Büttner et al. (2017) report that HMDs are too heavy and that the user experience is hindered by either a cable or limited battery capacities. Moreover, the acceptance among workers is sometimes hindered by hardware issues causing limited trust in the system or the fear of being controlled (Büttner et al. 2017). For the training of maintenance tasks, Scott et al. (2020) studied the technology readiness of companies and user acceptance of virtual environments. The framework they developed includes organisational factors and the learning situation in close connection with the design of the learning environment.

The limitations caused by the technology maturity can be summarised in a cause-and-effect diagram and sorted into the categories of measurements, materials, methods, machines, personnel, and environment (Figure 2).

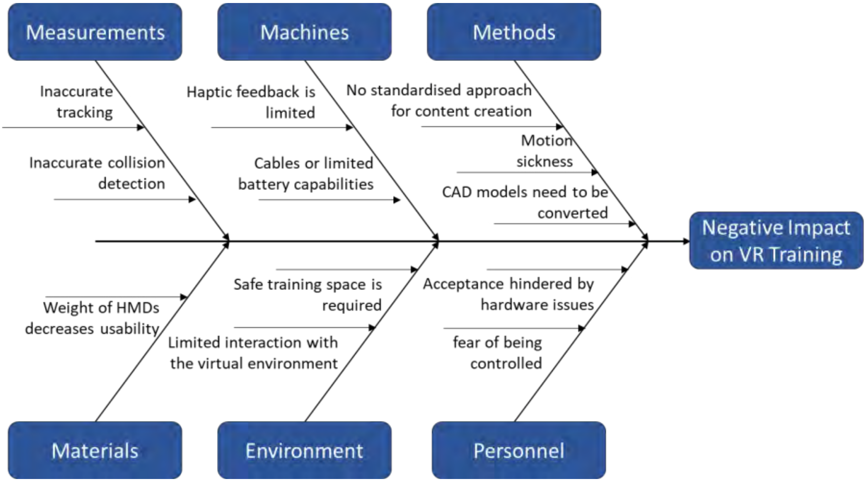

Figure 2: Technology maturity-related challenges of VR Training

Many of the aforementioned causes affect the user's interaction with the VR system. Inaccurate tracking leads to poor recognition of the users' interactions with the virtual environment. Cables prevent users from moving freely, and the weight of the headsets directly affects users' comfort during use. These technical limitations must be taken into account when designing the user interfaces, since user immersion and user acceptance depend to a large extent on the design of the user interface. The technical characteristics of the current hardware turn out to be a limiting factor for the design of the user interface and, therefore, cannot be disregarded.

4 Guidelines for user interface design of VR environments

Multiple sources list design guidelines that can be applied to user interfaces for VR systems.

ISO 9241-110 includes seven principles for the interaction design of interactive systems. The principles aim to improve the usability of the system regardless of the technology used. The individual principles are suitable for the user's tasks, self-descriptiveness, conformity with expectations, learnability, controllability, and use error robustness and user engagement.

Further usability principles for the design of interactive systems come from Nielsen (2020). In his ten usability heuristics, Nielsen (2020) gives general recommendations for interactive systems design. Examples include avoiding errors, e.g., by having users confirm an action or limiting the user interface from the essential information through an aesthetic and minimalistic design (Nielsen, 2020). Similar guidelines represent Shneiderman's eight golden rules of interface design. Like Nielsen's heuristics, these include recommendations to provide users with system-side feedback on the current status or reduce users' cognitive load by providing only relevant information. In his fundamental interaction principles, Norman guides human-system interaction usability, which essentially corresponds to the previously mentioned guidelines (Norman 2016).

The described guidelines refer to the design of currently dominant graphical user interfaces for 2D screen environments. Mixed Reality (MR) applications pose extended requirements for user interface design due to the high number of possible interaction forms, hardware configurations, and the possibility of addressing different senses (Dünser & Billinghurst 2011, Vi et al. 2019). Furthermore, in the context of the user experience of immersive technologies, the enabling of a sense of presence, which is related to the degree of immersion, as well as effects of motion sickness, are mentioned (Mütterlein & Hess 2017).

With this in mind, Vi et al. (2019) analysed existing guidelines and contributions for developing user interfaces for Extended Reality (XR) applications and derived eleven guidelines. These guidelines are related to the user experience of HMDs in XR environments and were correlated and adjusted with the usability guidelines of ISO 9241-110, Nielsen and Shneiderman. Therefore, for this research, the guidelines provide a reasonable basis for evaluating a VR-based training environment. These guidelines take into account, among other things, the technical maturity of the available VR hardware and thus address the previously described limitations for the design of user interfaces. The evaluation of the guidelines of Vi et al. (2019) on a practical example is still pending. With this paper, the authors want to contribute to the application of these guidelines and to establish a relation to a VR-based training example. This article cannot provide a complete evaluation of the guidelines based on user studies. In the following, a short summary of each guideline is presented to describe the respective contents, as these guidelines are discussed against the developed VR training environment in chapter 5.3. (Vi et al. 2019).

1. Organise the Spatial Environment to Maximise Efficiency: This guideline addresses the efficient use of three-dimensional space in XR applications. Content must be placed to the users in such a way that the additional space is used optimally, while at the same time the cognitive load of the users remains low and the physical movements are in proportion to the task.

2. Create Flexible Interactions and Environments: The designers need to consider different experience levels of the users and possible physical limitations. Ease of use and general satisfaction with the solution can be increased by adapting the settings to the users' needs.

3. Prioritise User's Comfort: This guideline addresses the user's comfort regarding physical, mental, and environmental influences on the user experience in an immersive environment. The designers can reach this by respecting distances when fading in virtual content, avoiding motion sickness, taking into account the hardware manufacturer's specifications, and producing a suitable environment for using the XR solution.

4. Keep it Simple: A virtual environment's particular challenge is to find the balance between enhancing the virtual experience and overwhelming the user. The information density in the field of view should be kept as low as possible.

5. Design Around Hardware Capabilities and Limitations: Designers must adapt the features of the solution to the hardware used and emphasise the strengths of the respective hardware to minimise the influence of the hardware limitations on the user experience.

6. Use Cues to Help Users Throughout Their Experience: Cues and sufficient user guidance can reduce the risk of overwhelming users. These cues include, for example, the use of directional cues to point out objects outside the direct line of sight. Furthermore, designers should make it easier for users to choose actions by providing concrete hints about the next steps or possible actions. In this context, designers should avoid the overuse of notifications.

7. Create a Compelling XR Experience: The application designers can intensify the user's immersion in the virtual environment by combining visual, auditory, and narrative elements.

8. Build Upon Real-World Knowledge: The design of virtual environments, interactions, and elements should be based on familiar patterns from the user's real-world environment to understand the application. Specific references extend to the interaction design with virtual objects in analogy to real objects of the same kind that actions trigger an expected reaction of the virtual objects.

9. Provide Feedback and Consistency: Consistent implementation of the feedback functions can make the possibilities of the application clear to the users. In particular, this involves the visual representation of different statuses of interactions, the display of results of an action or interaction by the user.

10. Allow Users to Feel in Control of the Experience: The application should gain users' trust by giving them control over the virtual environment's actions and reactions. Users should always be able to undo an unwanted action or leave an undesirable situation.

11. Allow for Trial and Error: Operator errors should not have irreversible consequences. An essential point in this context is the possibility of reversing actions by the users if errors happen in the application. In this way, users' anxiety in using the application can be reduced, and the discovery of system functions can be made possible.

5 Discussion of technical challenges and design guidelines

The identified technical challenges and design guidelines are discussed against a VR application on electrical safety training developed and implemented in collaboration with industrial stakeholders in 2020 (Figure 3).

Figure 3: VR training on electrical safety

5.1 Introduction to the training scenario

The scenario is intended for the safety training of young professionals, as well as a supplement to the yearly safety training of electricians that are mandatory in Germany (VDE 0105-100:2015-10) and multiple other European countries.

The scenario teaches the general safety rules for electrical safety on practical examples to provide an interactive and more engaging learning experience than a conventional lecture. The safety rules are implemented as steps that must be performed to progress within the training simulation safely. The most important steps are:

- To disconnect completely.
- To prevent reactivation.
- To make sure that the installation is dead.

These steps are also covered within the briefing of the scenario as basic learning targets for the training. A support function can always be activated to hint towards the next steps. From previous experiences, the best training results are achieved when the VR training is combined with a brief lecture on the topic. Therefore, the presented scenario consists of a tutorial and the actual exercise.

The tutorial is intended to teach the basic movement and object manipulation functions. The trainee must move towards a specific location and is tasked to pick up a screwdriver from a table and put it on a tool board, which completes the tutorial.

The exercise is to replace a broken electric engine on the shop floor. The task briefing is performed by a female foreman in case the audio help is activated. The steps are described in the following.

Read job ticket: The first step is to advance towards the table and read the job ticket. It hints at the location of the damaged engine.

Tool selection: The trainee is supposed to select the right tools for the job. The tools suspended on the wall can be grabbed with the virtual hands and put into snap zones within the toolbox (Figure 4). However, some tools are not required or are unsafe. The tools that must be put into the toolbox to advance to the next step are:

- a padlock,
- an interlock for fuse deactivation,
- a screwdriver for electric maintenance,
- a multimeter,
- a warning sign for ongoing maintenance activities.

Figure 4: Tool selection

View part number: After the tools are selected, the next step is to exit the room and locate the broken engine on the shop floor. The job ticket indicates that the engine is in field M2 (see Figure 5). The number corresponds to red markings on the pillars within the factory. The engine can also be found by looking for a broken part that emits smoke. It also has a worker standing next to it with a spare part. The trainee must then view the part number to identify the corresponding control cabinet and fuse. The number (N22M3) is written in red below the socket (see Figure 5). It indicates the number of the control cabinet (N20), the switch row within the cabinet (N22), and the fuse (M3).

Figure 5: Area designations on the shop floor

Open control cabinet: Before the engine can be repaired, it must be disconnected. Therefore, the trainee must locate and open the control cabinet located close to the starting area. Both doors must be opened.

Deactivate fuse: Inside the control cabinet, the fuse that corresponds to the broken engine must be deactivated.

Secure fuse: The deactivated fuse must then be secured against reactivation with the fuse interlock followed by the padlock.

Close control cabinet: After the fuse is secured, the control cabinet doors must be closed.

Attach warning sign: The next step is to attach a warning sign outside the control cabinet.

Ensure that the engine is disconnected: After the engine is disconnected, the trainee must ensure that the installation is dead. Therefore, the trainee should first use the screwdriver to unscrew one screw from the engine cover. The screwdriver will snap in position and can be pulled up to loosen the screw. Then, the cover must be removed and placed to the left. The multimeter can then be placed on top of the cover next to the broken engine. It will snap into position as well. Afterwards, an interface can be used to configure the multimeter setting. It must be set to detect alternating voltage. The measuring tips can then be placed inside the engine to create measurements. All connected contacts must be checked. Afterwards, the multimeter must be switched off and placed back into the toolbox.

Replace broken engine: The broken engine is replaced by touching the new engine on the palette. This action automatically replaces the broken engine.

Open control cabinet: After the new engine is in place, the trainee must again move to the control cabinet and open it.

Reactivate fuse: Inside the control cabinet, the security measures (interlock and padlock) must be moved back into the toolbox so that the fuse can be switched back on.

Close control cabinet: The control cabinet must then be closed.

Remove warning sign: The warning sign must be removed from the door of the control cabinet.

Check functionality: After the fuse is reconnected, the trainee must ensure that the installation is working. Again, this is done by moving back to the engine, moving the cover to the left side, and placing the multimeter right on top. The multimeter must again be set to detect alternating voltage. The measuring tips can then be placed inside the socket to create the measurement. It should measure different voltages depending on the placement of the measurement tips. Afterwards, the multimeter must be switched off and placed back into the toolbox. The cover must then be placed back onto the engine. The exercise is completed by moving back to the briefing room.

5.2 Discussion of technological challenges

The VR training scenario has been tested in two scenarios:

- Tests alongside the development have been performed by researchers (n=2) in a lab environment with Valve Index HMDs,
- Tests with the final build have been performed by industrial trainees (n=15) in a VR training room with HTC VIVE Cosmos Elite systems.

The test results allow for a discussion of the technological challenges identified in chapter 3 and the maturity of the applied VR hardware.

The training focuses on the procedural knowledge required for maintenance tasks. Haptic feedback is not a requirement. Nevertheless, the trainees experienced difficulties detecting the controller location on both types of devices when the connection to the base stations was impaired. An error was reported when the controller network of the Valve Index interfered with the Wireless Local Area

Network connection when both networks were sending at approximately 2.4 GHz.

Another interoperability issue occurred when the training scenario that has been initially developed for the HTC Vive Cosmos Elite was used with a Valve Index system. The different controller layouts of these systems caused the menu to pop up when the controller was squeezed, making a reconfiguration necessary.

The training scenario uses warping as the only movement option. Although warping lowers the occurrence of motion sickness, some trainees reported slight dizziness. The weight of the HMDs was not an issue due to the relatively short individual training time. However, the HMDs tend to heat up during long usage periods.

In general, the VR hardware received very positive feedback, although the described issues show that the technology is still in a relatively early stage and heavily suffers from interoperability issues.

5.3 Discussion of guidelines

This section evaluates the guidelines from Vi et al. (2019) based on the experiences made with the VR training scenario.

Guideline 1: Organize the Spatial Environment to Maximize Efficiency

The relevant objects are grouped at three locations: Tools are collected at a tool bench, the maintenance is performed at a damaged part within the factory, and the damaged devices are disconnected at a control cabinet. At these locations, all objects are placed to be clearly visible.

Although the orientation within the virtual environment is part of the task, the users' movement and orientation within the virtual space are free and not predictable. The virtual factory environment has been separated into zones as it is common practice in larger factories (Figure 5). During the testing, no user had severe issues navigating the factory once the movement controls were understood.

Guideline 2: Create Flexible Interactions and Environments

Multiple options are available to adjust the VR training scenario to individual needs. A customisation screen allows selecting the scenario, the language, pathfinding, visual, and auditive assistance (Figure 6).

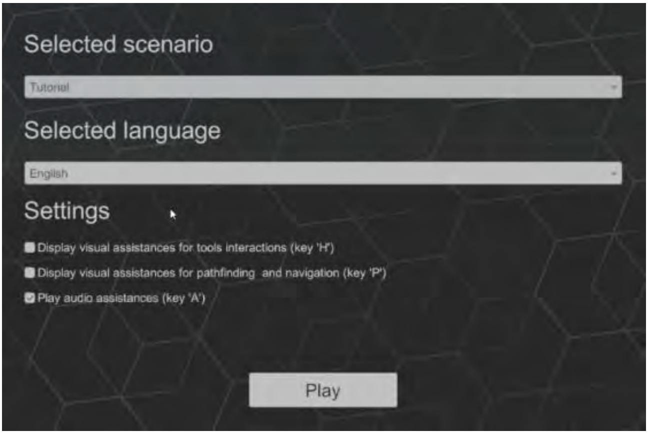

Figure 6: Customisation screen

Every user of the VR training within the test had at least an initial understanding of the task and the required steps. Because the VR training was performed under the guidance of a real trainer, the visual assistance and the pathfinding assistance (Figure 7) were used mainly for debugging. Nevertheless, the assistance functions are expected to provide viable guidance for new users.

Figure 7: Movement tutorial

Guideline 3: Prioritize User's Comfort

The user can move within the virtual space by walking, but the task requires movement between greater distances within the virtual environment. The training has been designed with warping as the only traversing option to minimise motion sickness (Figure 8).

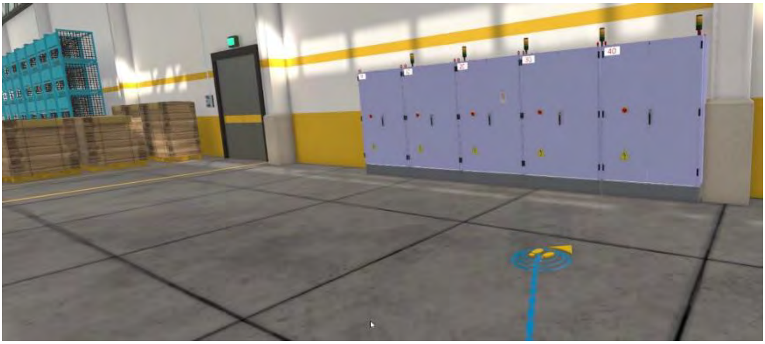

Figure 8: Movement by Warping

It is important to integrate warping or similar functions to prevent motion sickness or other forms of distress in industrial VR training applications.

Guideline 4: Keep it Simple: Do Not Overwhelm the User

The training has been designed to provide training on safety rules for electrical maintenance under realistic circumstances. The user receives audio and notifications intended to induce a moderate amount of stress to train the recollection of the safety rules in a stressful situation. Therefore, training purposes may require a design to challenge a trainee intentionally.

Guideline 5: Design Around Hardware Capabilities and Limitations

Hardware limitations have been less of an issue during the VR training scenario than the available 3D assets and development budget. Some of the hardware-related issues have been discussed in Section 5.2.

Guideline 6: Use Cues to Help Users Throughout Their Experience

The training is augmented with optional visual and auditory cues that guide the trainee to the next step. The auditory cues are given by a virtual foreman that conveys and further describes the task. The visual guidance is displayed as ghost objects that indicate the target position of objects and tools (Figure 9).

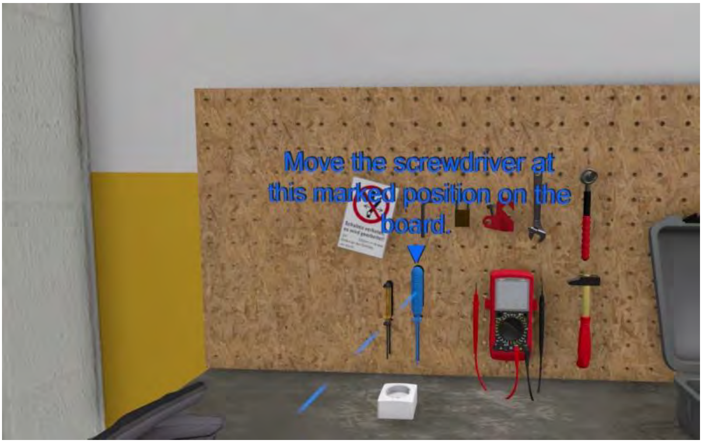

Figure 9: Optional visual guidance

Although guiding functions were included, the training personnel preferred to guide the trainees during the VR training.

Guideline 7: Create a Compelling XR Experience

The guideline appears to be generic yet important for immersion. The VR training has been designed to convey a realistic experience of an actual maintenance task. The story is set by a character acting as a foreman who provides the task and asks the trainee to solve it as fast as possible. The training is further augmented by ambient noises and decorative objects that build the scenery.

Guideline 8: Build Upon Real-World Knowledge

Combining real-world knowledge must be considered an obvious requirement for any industrial training simulation that intends to train cognitive skills. Training can only be performed if the design of the virtual experience corresponds to its real counterpart. The maintenance safety scenario has therefore been designed in collaboration with an industrial end-user and training personnel.

Guideline 9: Provide Feedback and Consistency

The VR maintenance training scenario features a broken electrical engine and aims to provide consistent feedback. For example, the trainee receives a simulated shock effect via auditory and visual cues if electrified engine parts are touched. The shock effect does not appear if the engine is disconnected.

It has been established that an industrial training simulation requires a certain functional fidelity towards the trained task (Alessi 2000, Hathaway & Cross 2016). Otherwise, the trained skills would not be transferable to the real system.

Guideline 10: Allow Users to Feel in Control of the Experience

This guideline can only partially apply to training scenarios. For didactic purposes, it can be beneficial to visualise the consequences of mistakes to the trainee. These consequences can include scenes that occur because of the users' actions but are now out of the users' control.

For instance, during the VR maintenance training simulation design, the trainers requested an injured coworker to appear if the trainee fails to install warning signs.

Guideline 11: Allow for Trial and Error

A major benefit of simulation-based training is learning about the system’s behaviour through a trial and error approach. Compared to errorless learning, training through a trial and error method is considered to allow for an easier transfer into practice (Jones et al. 2010).

6 Summary

The analysis has shown that Virtual Reality (VR) still suffers from issues that indicate a relatively low technological maturity. Nevertheless, VR technology has already been improved greatly and can provide an actual benefit in industrial practice. VR is currently emerging into industrial training practice, which indicates a considerable demand and potential for the technology to grow. Hardware costs were the focal challenge of VR in the earlier years that is now mostly resolved. The next layer of challenges includes multiple issues such as standardisation and interoperability in hardware and content creation. The effort required for the creation and customization of content for VR training is a major challenge. Companies that intend to implement VR training in their vocational training usually require external resources. Inter-organizational barriers and a lack of standardization hinder future content updates in VR applications .

This research has also discussed guidelines from Vi et al. (2019) as a possible design framework for VR training scenarios. The results indicate that some guidelines are beneficial; others are relatively generic or only partially apply to the design of training simulations for industrial applications. These findings can be observed for the development of virtual environments for industrial use cases in a very similar way in the context of AR applications (Stern et al. 2020). The technical maturity of the available hardware as well as the lack of explicit guidelines for the design of three-dimensional user interfaces pose great challenges for the development of usable virtual applications. Further insights into the acceptance, especially with regard to the design of user interfaces of VR-based training, must be gained by testing the developed systems in practice. Formal user studies can provide further insights into the design of VR training environments. The users' requirements depend strongly on the application case, but the guidelines offer an useful orientation to avoid basic mistakes in the design of virtual applications. Therefore, the authors aim to evaluate developed VR training with users in a formal user study to draw further conclusions on usability and user experience. Furthermore, a user study would provide further insights on the general design of XR applications and the effectiveness of the applied guidelines.

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AI-supported assistance systems in enterprise learning processes - prospects and limitations

Norbert Gronau, Gergana Vladova

1. Introduction

Artificial intelligence is used today in processes of learning and knowledge transfer – to assess learning outcomes, make recommendations, close learning gaps, or adapt learning to individual needs. It is assumed that the role of artificial intelligence in human learning will increase, that AI will takes over the active tasks of a teacher, and will also be able to support the creative and socio-emotional aspects of learning. This is a promising expectation, in view of the fact that education is a social good of enormous importance in today's world. Learners are increasing in number and diversity - school education is compulsory, colleges and universities are increasingly attended, continuing education and lifelong learning are not the exceptions for organizations, but rather the norm. Educators are faced with new challenges that go beyond imparting knowledge: individualization and personalization of learning as well as differentiation in the classroom; equal education for all; active participation of the learners instead of passive knowledge transfer from teacher to the learner; development of competencies that are crucial in today's world, such as problem solving, critical or creative thinking.

These challenges affect all educational contexts equally. However, this paper focuses specifically on learning processes in companies and the role of AI in them, especially in the context of the use of cognitive assistance systems (AS).

People remain the critical success factor for companies in the factory of the future, but their potential must be developed on the basis of individual dispositions - knowledge, skills and acceptance. When AI is used in production processes - in contrast to classic automation - people are not replaced by technology, but rather supported. The goal is to expand the work capacities of employees or to compensate for missing skills. The increasing degree of digitalization and networking as well as the tasks and responsibilities are becoming more and more complex. Employees perform their tasks in a complex collaborative network environment that is not only connected to people but also to information and communication technologies and assistance systems, which requires new specific knowledge and competences as well as corresponding didactic concepts and learning environments (Gronau et al. 2017).

AS serve the application-oriented, near-real-time provision of information to support employees in decision-making or to guide them in manual tasks. Cognitive

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AS are encountered by employees in the form of various artefacts - mobile devices, stationary displays on which the ASs are presented as more or less interactive visualization systems, wearables such as data glasses (Vladova at al. 2020). AS can support employees in learning new tasks by filtering the information relevant to the process and making it available as needed, thus offering potential for faster and work-integrated competence development (Senderek/Geisler 2015). For companies, this not only offers the advantage that employees' work activities and work performance can be directly controlled and optimized from an efficiency perspective. It also enables the flexible adaptation of work processes to new procedures and changing products and makes staff deployment and recruitment much more flexible. This digital employee management offers various advantages for companies, such as direct control and optimization of employees' work activities and work performance (especially low-skilled employees), flexible adaptation of work processes to new procedures and changing products, flexible staff deployment (Kuhlmann et al. 2018). In the enterprise context, AI can also be directly used to create simulated or individualized learning environments.

The major changes in the industrial world have been caused by the concepts of Industry 4.0 and the Smart Factory (Rauch et al. 2020). People, machines and products are networked and together form a new production system in which workers and robots work together and supported by web technology and intelligent assistance systems, and information and knowledge are exchanged more quickly and efficiently. In the manufacturing execution phase of a cyber-physical production system, different approaches of cognitive assistance were identified, with decision support systems, digital information assistance systems, virtual training, augmented and virtual reality assistance, and IT-based knowledge transfer systems directly addressing the importance of assistance technology for learning and knowledge transfer activities. Rauch et al. (2020) points out, among other things, the possibilities for enhancement of cognitive abilities and skill development of technology users as well as for information support through the system (e.g. Corbett 1990; Hirsch et al. 1992; Fan/Gassmann 1995; Fujita et al. 2009; Mital/Pennathur 1999). The worker is mainly seen as an active consumer and provider of information, acting within knowledge brokerage and skill transfer systems (Gorecky at al. 2013). The system can support the user in different ways to meet the challenges of working in new, very flexible and data-rich environments: e.g. with augmented reality (Paelke 2014), head-worn displays (e.g. Rauh et al. 2015), virtual training systems (Gorecky et al.)

As in any other context, the use of AI in learning processes also involves risks and challenges. Goals such as the individualization of learning can only be achieved to a limited extent, and the question of which learner characteristics need to be taken into account and how they can be captured has not yet been answered in research and practice.

In this paper we address the opportunities and challenges of cognitive AS in the context of workplace learning. In chapter two, we first discuss against the state of the art perspectives of AI-supported assistance systems, especially with regard to process support and the support of specific employee groups. In a next step, we specify the limitations of these systems in chapter three. In the final chapter, we summarize these findings and identify opportunities and necessities for future development as well as essential areas of work for further research on the use of AI in industrial processes.

2. Prospects of AI-supported assistance systems

Gorecky et al. (2014, p. 90) describe employees as the "most flexible part of the production system" that must "constantly adapt to new and changing technology trends". According to the authors, these trends fall into five main categories: demographic change (skills shortages, ageing and changing workforce); globalization (new and changing markets, emerging competition); changing customer demands (product diversity, personalized customer solution, emerging competition); rapid technological developments (adaptation to new technologies, shorter product life cycles); and knowledge economy (knowledge as a productive asset). Therefore, organizations need to learn how to benefit from the positive effects and potential of ICT-based training and knowledge sharing at the individual and organizational level. Required competencies and qualifications can be easily taught, satisfaction and motivation can be increased; for organizations, the full potential of employees can be tapped. The use of assistance systems in the manufacturing context opens up new possibilities for learning approaches such as situational learning. Learning takes place continuously and as part of the work process and the learner interacts actively with the learning environment instead of being a passive recipient (compared to classical VET activities). Training is ad-hoc and on-the-job and uses digital media and educational technologies in imparting knowledge and developing skills. In the future factory, the role and tasks of teachers, mentors and experts are expected to be complemented and supported by smart information technologies (Gorecky et al. 2014). However, these changes influence existing process structures and procedures and are associated with changes and challenges.

2.1. Process-related prospects

Many assistance systems for the enterprise context currently exist and are under development. In general, they can be divided into physical assistance systems (systems that support the worker in physiological work), sensory assistance systems (systems that collect and provide data) and cognitive systems (Romero et al., 2016). The area of cognitive aids for the execution of production systems represents the main research topic in the context of companies. These systems represent new opportunities for virtual training using virtual reality technologies, with dramatic improvements in the learning process and outcomes (Rauch et al. 2020).

Rauch et al. (2020) see the use of assistance systems for learning and information provision as a research focus within Industrie 4.0. Here, the systems can be viewed from two different angles: They support both the human worker in the factory of the future, and they define new challenges for the human worker, requiring new skills and competences to create a collaborative learning environment for both - human and technology. Depending on the adaptivity of the system with regard to the selection of assistance measures, a cognitive assistance system in a can be used both for the induction of new employees into work processes and for quality management and general assistance tasks for professional, experienced employees (Halsgrübler et al. 2018).

According to Gorecky et al. (2014, p. 92), assistance in the work context "aims at high output (...) by guiding a person to imitate a certain behaviour, e.g. in the form of detailed procedural, step-by-step instructions". The focus of learning, on the other hand, is on pedagogical objectives and effective repetition with the long-term goal of broadening the worker's experience and general understanding of a task or related tasks. However, assistance and learning in a manufacturing context are becoming more similar, with both initial peak performance on an unfamiliar task and skill development being important. An assistance system (for training and knowledge sharing) can combine both goals - full assistance can be offered at the beginning and gradually removed. Eiriksdottir/Catrambone 2011 analyze the influence of instruction type on initial performance as well as on learning and transfer and present a structured overview of the factors that help or hurt in both cases. According to this review, procedural instructions can help in the context of initial performance by providing specific step descriptions, supplementing general step descriptions with examples, or providing specific goals. However, the same negatively influence the procedural instruction process in learning and transfer. General step descriptions are counterproductive in the context of procedural instruction for initial implementation. On the other hand, general step descriptions are helpful when learning and transfer are the focus of the instruction. Differences were also found in the use of principles and examples (more similarity to the task in initial performance vs. use of examples without support to guide generalization within learning and training).

This is in line with the results of an experiment that combines both - the transfer of general, process-related information, as well as of specific task knowledge (Vladova at al. 2020). In a learning factory, a highly automated work process was simulated in which human workers are responsible for operating the machines (setting the parameters, starting the work program, inserting the workpieces) and loading and observing the machines. Assistance systems were used to guide the workers/probands, which, similar to a navigation device in a car, inform the workers exactly which activities they have to carry out and when. The focus was on testing whether having a good knowledge of the entire work process has an influence on productivity and quality of work as well as on the motivation and satisfaction of the participants. The results suggest that while digital assistance systems can enable hands-on learning, there is a risk that the holistic knowledge of the work process itself is lost and thus has a negative impact on employees' work performance, motivation and satisfaction. It has been shown that additional knowledge about the production process has a positive impact, especially on high-performing participants.

Gorecky et al. (2011) see personal assistance systems as crucial to strengthening the role of humans in production environments. In this context, technologies for capturing and learning cognitive behaviours and activities of human users in particular will gain importance in order to develop cognitive understanding in user assistance systems.

Assistance systems can be used for process analysis along production chains in Industrie 4.0 environments. Barig/Balzereit (2019) discuss an efficient approach for this with a combination of process-related local and a global assistance system. Local assistants, connected to machine modules, learn and analyze the production processes with artificial intelligence (AI) methods. Their results are used by the global assistance system to obtain a central overview of the entire production chain. In this way, the global system can send information about errors and possible causes to the users and thus avoid long production stoppages due to root cause analyses.

Minhas/Berger (2012) discuss the potential of an ontology-based intelligent assistance system to support the planner in the environmental assessment of custom manufacturing. in decentralized manufacturing networks as well as in production planning decision making. Given the complexity of manufacturing processes and the growing amount of data, workers struggle with the challenge of process monitoring, data analysis and error detection. This leads to delayed problem detection, short maintenance intervals and insufficient use of optimization potential (Windmann et al. 2015). Self-learning assistance systems can observe complex manufacturing processes and automatically detect errors, anomalies and optimization needs (ibid.).

Gorecky et al. (2011) show the potential of a cognitive assistance and training system based on state-of-the-art techniques of motion and object tracking, task analysis, decision making and user-adaptive visualization via augmented reality in an industrial context. The authors use the example of a system that is able to give instructions to workers during the process and to understand and initiate human workflows. The system observes advanced users using high sensory capabilities to automatically analyze and capture assembly sequences. In a next step, an in-system understanding of assembly operations is developed and the system can use the captured knowledge to assist and train inexperienced workers. A similar idea is presented by Bleser et al. (2018). They discuss the development of a concept and demonstrator with the aim of learning workflows by observing multiple experts and transferring the learned workflow models to inexperienced users.

Breitsprecher/Wartzack (2012) report on the development of a self-learning assistance system and show the potential of a knowledge-based assistance system as an extensive area of research in various domains, with the common idea being to map the knowledge of an expert in a computer, store it and use it to emulate problem solving.

Assistance systems can furthermore be used to detect and reduce errors by directly learning what behaviour causes the errors. The main benefits are faster cycle times, reliability, reduced error rate and traceability in assisting the intelligent operator in real time. For example, AR can be used as a digital assistance system to reduce human error and dependence on printed work instructions, computer screens and operator memory as sources of information for a skilled worker (Romero et al. 2016).

2.2. Prospects for specific employees' groups

Aksu et al. (2018) and Drolshagen et al. (2021) describe how technical assistance can help employees with disabilities to work safely and complete their tasks without stress. Mark at al. (2018) discusses assistance as well as the categorization of user groups in the present Production 4.0. As a result of this market and literature review, the authors identify the need to match assistance systems to user groups and show how this is feasible.

Neumann et al. (2020) investigate the use of AR-enabled assistance systems tailored to the individual needs of workers with different cognitive and physical abilities in an industrial context and point out that the implementation of these assistance devices - in order to be successful - should include user- and value-oriented system design and change management strategies, especially information and participation, which would lead to a better congruence of technology features with those of the workers.

Sahlab /Jazdi (2020) discuss the challenge of developing user-adaptive assistance systems in dynamic environments, especially in the context of demographic change (Teichmann et al. 2019).

Aehnelt/Bader (2015) build on the idea that people do their work faster and better when they use a detailed work plan to orient and structure their tasks (Kokkalis et al. 2013) and describe the positive effect of intelligent systems that autonomously create work plans, make them available to workers and monitor their work. The information on assembly processes provided by the assistance system enables low-skilled workers to produce high-quality products and remain motivated. The authors describe five general types of information support provided by the system: awareness, guidance, monitoring, documentation and guarding.

3. Limitations of AI-supported assistance systems

Cognitive technical systems are equipped with artificial sensors and actuators and differ from other technical systems through cognitive control mechanisms and cognitive abilities. They integrate themselves into physical systems in a real environment (cf. also below Zäh et al. 2007). Cognitive control mechanisms are understood as the ability to exhibit and develop back-referenced and situational behaviours in accordance with long-term intentions. Their cognitive abilities - perceiving, reasoning, learning and planning - make these systems suitable for the following activities:

- drawing conclusions from knowledge;
- learn from its experiences;
- being able to explain oneself and explain to one what its task;
- be aware of one's own abilities and use them in one's the context of one's behaviour;
- reacts robustly to unforeseen situations.

The goal of cognition is to improve the interaction between people and technical systems while making the overall process more robust, flexible and efficient, which is particularly important in the context of production. The fulfilment of these demanding tasks depends to a large extent on the development of technology and the skills and competences of the employees who work together with the technology.

Kokkalis et al. (2013) show the potential of automatic generation of work plans. However, the authors point out that different tasks may be performed by different technical or non-technical units, which should be recognized and indicated by the assistance system.

As a further limitation for the use of AI-based assistance systems, Neumann et al. (2020) emphasize the importance of distinct "self-explanatory" features of (AR-based) assistance systems as well as the quality of the implementation strategy. Users' trust in the system's performance depends, among other things, on their satisfaction with the communication of the features and the system. One way to overcome this problem is to make users aware of such issues during the introduction and coaching phase. The usability of systems (according to TAM (Davis 1989)) has been shown to depend on users' prior experience with technology (AR). Therefore, when designing the systems, special attention should be paid to user-friendly presented instructions and well-coordinated training of future users in the use of the system.

In order to achieve the goals intelligently and successfully, the assistance systems need corresponding information. This can be found, for example, in production data management systems, although the formalization and externalization of procedural and conceptual knowledge remains a major challenge for organizations (Aehnelt/Bader 2015).

Chacón et al. (2020) see humans as generally superior due to their cognitive abilities, but machines as much better at performing repetitive, heavy-load tasks with high precision and reliability. Cognitive systems have the potential to provide the best possible support with minimum necessary interruption. Guidance can be provided as needed and according to the skills of the worker (e.g. trainee versus experienced worker). In addition, newcomers can be trained in on-the-job training scenarios and integrated directly into production.

4. Conclusions

The authors of this paper see three major areas of work for the better study of the use of AI in industrial processes:

First, the mainly used theories of learning and teaching were developed before the digital transformation started and AI technologies emerged. Therefore, there is an urgent need for a holistic theory, or at least a model, that will make it possible to explain the changes that AI brings separately in terms of teachers, learners, content, teaching/learning mode and, last but not least, learning outcomes.

Secondly, it will be necessary to describe and control the non-linear influence of AI on the whole learning process. When AI is used to teach and help the teacher and the learner at the same time, there can be a non-linear evolution of the teaching and learning process. This is not seen in today's teaching environment as it does not adapt to the teacher or the learner.

Thirdly and most importantly, we need to test new approaches in real-world environments. Learning factories could be a very good start because some of them also have an adaptive environment.

Undoubtedly, the undisputed use of AI in teaching and learning will improve the learning process, sometimes in ways that we cannot clearly see today.

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A Learning Assistance System for the Ergonomic Behavioural Prevention in Production

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1. Introduction

Musculoskeletal disorders (MSDs) are the major cause for incapacity for work in the German production industry (BAuA 2019), and health problems of the upper extremeties and lower back account for around 39 % of occupational diseases in Europe (van Eerd et al. 2016). Thus, ergonomic work processes are especially important in order to protect the workers' health and reduce high follow-up costs for companies and society.

Therefore, on the one hand, it is necessary to make workplaces more ergonomic (so-called organisational prevention). On the other hand, workers need to be trained how to carry out work processes ergonomically and thus optimise their individual behaviour at the workplace (so-called behavioural prevention) (Halbe-Haenschke 2017). While digital ergonomics analyses for organisational prevention increase in popularity, modern technologies are mainly used to control different health risk factors in behavioural prevention, such as body weight, nutrition and physical activity (Pfaff/Zeike 2017).

A comprehensive ergonomics analysis would account for the workers' individual physical ability, ergonomic work processes as well as the individual strain on the worker caused by the work processes. However, with the methods available today, it would be too time-consuming and often too slow to allow short-cycle learning.

The goal of the learning assistance system (LAS) described below is to enable such an analysis with the help of a motion capture system. For this purpose, an employee trained in the method carries out a capability and workplace analysis with the production worker.

The paper is structured as follows: chapter 2 describes the theoretical background and chapter 3 shows the LAS' structure. Subsequently, the capability analysis (chapter 4) and workplace analysis (chapter 5) are presented. The paper closes with a summary and outlook (chapter 6).

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2. Theoretical Background

2.1. Behavioural and organisational prevention

Behavioural prevention aims to minimise behaviour that poses a risk to health and to promote health literacy as well as healthy and safe behaviour. Corporate health management usually focusses on information events, presentations, workshops and seminars for behavioural prevention (Halbe-Haenschke 2017) even though this traditional form of health education and instruction shows little effect (Richter/Rosenbrock 2014). This is due to the fact that little use is made of behavioural preventive measures and that they often do not reach the population groups with the greatest need (Jordan 2020).

Organisational prevention addresses the creation of a health-promoting environment. In ergonomics, the focus lies on ergonomic workplace design (Halbe-Hanschke 2017). In order to improve a workplace according to ergonomic aspects, a risk assessment needs to be carried out first. Occupational physical stress is assessed using screening methods, such as the Key Indicator Methods, the European Assembly Worksheet or the Rapid Upper Limb Assessment (RULA). The results can then be used to derive measures for an improved work design (BAuA 2019).

Because RULA assesses individual body postures and focusses on the upper extremities, it is particularly suitable to assess the individual behaviour in production processes. Based on selected joint angles and loads acting on the body, it determines a risk value that describes the risk of suffering an MSD. By relating it to specific body postures, RULA makes it easier to derive effective countermeasures (McAtamney/Nigel Corlett 1993).

2.2. Virtual Ergonomics

In the course of technological progress, virtual ergonomics is becoming increasingly important. With the help of digital human models (DHMs), computer-aided methods and tools can be used for the ergonomic design of products, work systems and processes (Mühlstedt 2016a). DHMs represent the geometry and other human properties and allow a digital manipulation of body postures using forward or inverse kinematics. In addition, it is possible to record human movements with motion capture systems and impose them on a DHM (Mühlstedt 2016b). The technologies mentioned above can be used to digitise the screening methods for organisational prevention described in 2.1. However, there are only a few approaches that use these methods for behavioural prevention, for example by evaluating the body posture in real time with a 3D camera and then providing feedback to the worker (e. g. Martin et al. 2012).

2.3. Capability Analyses

In the health sector and ergonomics, capability analyses are described as functional capacity evaluations. Two comprehensive methods have been established to determine the physical capabilities of an employee: the Functional Capacity Evaluation according to Isernhagen and the ERGOS work simulator (Oliveri 2006). Both methods use standardised tests to assess the subject's work-related physical capacity. Since they are very costly (~5 hours excluding the time for evaluations and reports), assessing the capabilities of an entire workforce is expensive and time-consuming. These methods are therefore mostly applied in occupational therapy contexts, for example, to secure a damage-free return to work after an illness or to quantify the course of rehabilitation (Kaiser et al. 2000; Oliveri 2006).

2.4. Mobility Analyses

Complex three-dimensional movements or movements in two dimensions can be used to assess mobility. When focusing on complex movements, it is often not obvious which joints and movements are deficient. Movement goals can be reached by means of compensatory movements, although a certain joint function is not given. If only the movement in 3D is analysed, joint angle maxima and mobility deficits around a movement axis may not be recognised. A reliable statement on the mobility of a joint is only possible by testing the range of motion (ROM) in 2D, as no compensatory movements influence the quality of movement. The problems of correctly recording joint mobility can be illustrated by the example of the shoulder:

The structure of the shoulder joint is a compromise between mobility and stability. A completely isolated movement in one plane is not possible since it is always a combination of multiple movements. During flexion and extension of the joint, there is always also a rotation of the humeral head and translations in the glenohumeral joint (Novotny et al. 1998; Stokdijk et al. 2003).

For the representation of joint mobility, the neutral zero method has become established. It is a standardised method to measure joint mobility and is based on movements in each plane of motion around the corresponding axis. For each degree of freedom, two different motions are possible, such as the flexion and extension or abduction and adduction of a joint (Schünke et al. 2018).

2.5. Correlation between grip strength and global muscle strength

Studies (Porto et al. 2019) show a significant positive correlation between handgrip strength and global muscle strength. Global muscle strength has various yet similar definitions: Porto et al. (2019) define it as the summation of the peak muscle torques of the trunk and dominant muscle groups of the lower extremities (see Figure 1). Tietjen-Smith et al. (2006) measure the global muscle strength by summing strength measures like shoulder press, bench press, back pull-down and knee extension and flexion. Wind et al. (2010) define it as the sum of shoulder abductors, hip flexors and ankle dorsiflexors. The different studies show significant positive correlations between grip strength and multiple muscle groups for healthy adults of both genders. Grip strength correlates significantly with the knee extensors and flexors and back strength and also with the maximum muscle torques of the trunk, hips, knees and ankles. Furthermore, there are gender-dependent differences. Men have higher handgrip strength values than women and the maximum handgrip strength decreases with age for both genders, after the maximum was reached between 30 and 40 years (Steiber 2016).

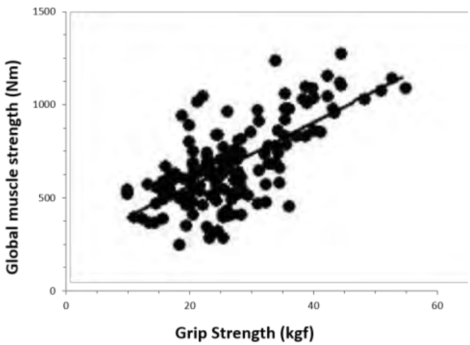


Figure 1: Correlation between global muscle strength and grip strength. Adapted from Porto et al. (2019).

3. Concept for the LAS

This chapter describes the structure of the proposed LAS, the derived requirements and the utilised hardware and software.

3.1. Structure

Figure 2 shows the schematic structure of the LAS. In the *capability analysis*, worker mobility and strength are measured in order to create a physical capability profile. This physical capability profile shows the worker's ability to move and his or her load-bearing capacity. In the course of the *workplace analysis*, the work processes and external loads acting on the worker are recorded in order to determine the workplace-induced stress. By comparing the worker's physical capabilities with the workplace-induced stress, the workplace-induced strain on the individual worker can be determined. This approach allows to derive different measures:

- Individual measures to generally increase the worker's strength and mobility can be derived from the employee's capabilities.

- Workplace-specific measures for all employees can be derived from the workplace-induced stress.

- Workplace-specific measures for individual worker can be derived from the strain.

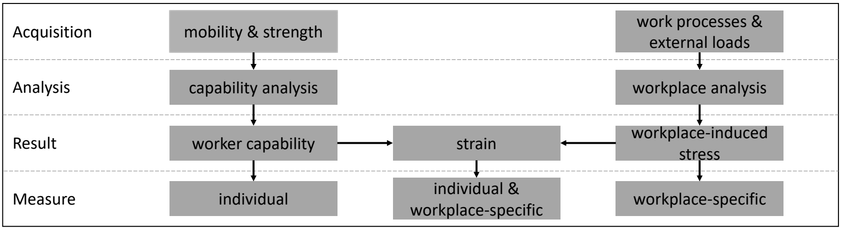


Figure 2: Schematic structure of the LAS

The structure and the field of application result in the following requirements for the capability and workplace analysis for an application in the LAS:

In order to meet the specific conditions of a company and to create a physical capability profile for an entire workforce or multiple chosen workers, the capability analysis has to be carried out in a significantly lower timeframe than the methods presented earlier. However, the capability profile needs to give a comprehensive picture of the individual worker's physical capabilities. The research goal was to find a suitable compromise between analysis effort and quality and to develop a method to measure the capabilities.

In order to prevent MSDs effectively, the workplace ergonomics needs to be assessed at an early stage. As described in section 2.1, existing ergonomics analyses aim at organisational prevention. The focus of the LAS is to improve the worker's behaviour at the workplace. Thus, it is necessary to assess individual postures and not the workplace as a whole. Furthermore, the analysis results have to be processed and visualised comprehensively to promote short learning cycles and quickly verify the effect of derived measures.

The use of the LAS requires two people: a staff member trained in the method and the production worker to be examined. The identification of critical work processes and the derivation of suitable measures require an advanced understanding of ergonomics, which is why it is generally not advisable for the production worker to use the system alone.

3.2. Utilised Hardware and Software

The kinematic data is captured with the XSens MVN Awinda motion capture system (Xsens MVN Awinda, Xsens Technology BV, Enschede, Netherlands). In contrast to camera-based systems, the inertial sensor system allows motion analysis at the workplace since the recording quality is not impaired by the occlusion of body parts by workpieces or machines. The kinematic information of the recorded human motion sequence (e.g. the position of 23 body segments) is extracted and converted using the corresponding software.

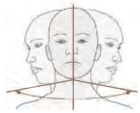
The software for the LAS was developed using the game engine Unity and allows a quick evaluation of the capability and workplace analysis. The external loads are tracked with a web application that records the weight class and the time stamp of grabbing and releasing workpieces or tools.

4. Capability Analysis

As described in section 3.1, a capability analysis needs to be performed in order to derive individual measures that improve the worker's capabilities if deficits are noted and adjust the work task to his or her needs. This chapter describes the capability analysis that is used to determine a worker's ability to move and his or her load-bearing capacity. The capability analysis comprises 14 standardised movement exercises (see Table 1) to assess joint mobility, and a grip strength measurement to estimate the global muscle status. The analysis takes approximately 30 minutes in total, which already includes taking body measurements and putting on the motion capture system. In order to minimise the time requirement, the use of a 3D camera for the mobility analysis was examined (Brosche et al. 2020) but the tracking algorithms could not achieve satisfactory results for all movement exercises. If technological progress allows the use of a 3D camera to record the movement exercises, the analysis duration can be reduced to 10 to 15 minutes.

4.1. Standardised movement exercises and application of the neutral zero method

For the mobility analysis, standardised movement exercises (see Table 1) are performed to identify deficits of single joints. The standardised exercises help to objectify existing restrictions by comparing the results of the neutral zero method with a standard ROM assessment. The individual mobility of the assessed joints can thus be compared to standard values from literature. Consequently, it is possible to provide individual feedback to the worker and assess his or her ability to move.

Joint	**Movement**		
Cervical spine	Flexion/ Extension 	Lateral flexion 	Rotation 

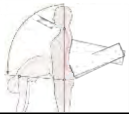
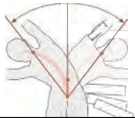
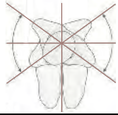
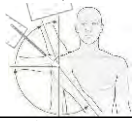
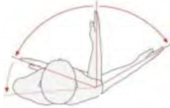
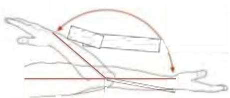
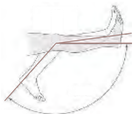
Thoracic and lumbar spine	Flexion 	Lateral flexion 	Rotation 
Shoulder	Flexion/ Extension 	Abduction/ Adduction 	
	External rotation 	External/ Internal rotation (abducted) 	
Elbow	Flexion 		
Wrist	Flexion/ Extension 	Abduction/ Adduction 	
Knee	Flexion 		

Table 1: Standardised movement exercises. Adapted from Schünke et al. (2018).

4.2. Grip strength indicating the load-bearing capacity

There is a significant positive correlation between handgrip strength and total muscle strength (see section 2.5). Therefore, the evaluation of grip strength can be used for an assessment of physical fitness or health status. The grip force is examined by means of a hand force dynamometer, an inexpensive standard measuring device. In comparison to the ERGOS work simulator, where the strength ability is tested on a larger scale, here the strength measurement is limited to the hand strength alone.

By using the measurement of grip strength as part of the capability analysis, statements can be made about the muscle status and health status of individual workers.

These individual statements can then be used to adapt global load limits to individual workers (see section 5.1).

4.3. Application of the capability analysis in the LAS

With the help of the mobility and hand force measurements from the capability analysis, a capability profile of the employee is created. In the LAS, the capability profile is initially viewed in isolation. With the help of a 3D representation of the generated DHM, possible limitations in mobility can be visualised in an easily understandable way and conspicuous joints can be quickly identified (see Figure 3). The joints are represented by spheres which are coloured based on the results of the mobility analysis. The joints with corresponding angles below the respective normal range are coloured yellow and the measured values are shown in relation to the lower limit of the normal range. Excessive joint mobility is not indicated due to the unrestricted movement execution. When discussing the results, particular attention needs to be paid to high deviations from the normal values and intraindividual differences.

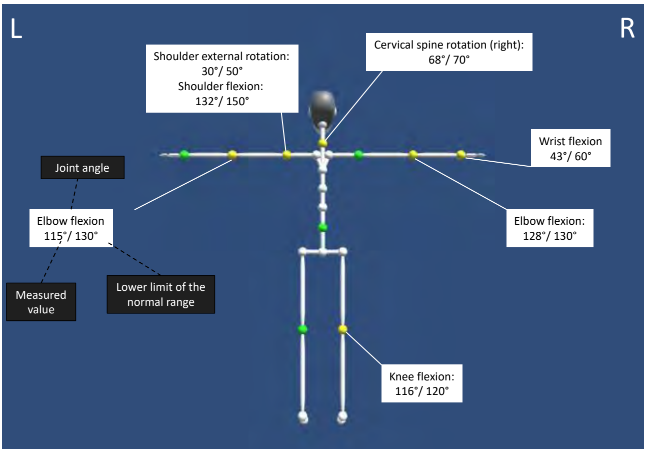


Figure 3: A traffic light system to visualise joint mobility

In the example in Figure 3, several measured values are below the standard ROM. Slightly falling below the lower limit of the normal range does not require any measures to be taken. This is the case for the cervical spine rotation, the right elbow flexion and right knee flexion from the example. In the case of greater deviations from the normal range, a follow-up examination by the company physician should follow. In the example, this would be the case for the external rotation and flexion of the left shoulder and for the left elbow flexion.

In addition, the grip strength measurement is discussed with the employee. Possible restrictions are only registered when a measured value for the right or left hand is below the age-specific normal value minus its standard deviation and can thus be classified as significantly low. If there are any abnormalities, a visit to the company doctor is recommended in order to carry out more detailed examinations. If necessary, targeted strength training could be initiated to improve overall muscle strength and the overall health status. By repeating the capability analysis regularly (e. g. every year), the workers' physical capabilities can be monitored and the effect of strength or mobility training can be checked.

The full capability analysis has so far been carried out with a sample of 7 people aged 33 to 56 in industry. In this small sample, several limitations in mobility were found and two significant deviations of hand strength from the normal value could be identified.

5. Workplace Analysis

After assessing the worker's individual capabilities, the workplace analysis is used to determine the stress of the workplace and the resulting physical strain on the worker. In order to meet the requirements mentioned in section 3.1, the workplace analysis consists of two different modules: The physical stress is determined with the help of the RULA and the calculation of joint torques. The strain results from the comparison of the worker's mobility with the joint angles occurring in the work process and by individualising the global joint torque limits in relation to the grip strength.

5.1. Physical stress

RULA is used as a tool for workplace analysis, as it enables an assessment of individual postures, focuses on the upper body and includes external loads in the ergonomics assessment. For the software implementation, the methodology described by McAtamney/Nigel Corlett (1993) was implemented with three restrictions. In order to keep the collection of metadata as simple as possible, arm support/ leaning and extra points due to static posture or repetition are not recorded. In addition, all loads are assumed to be intermittent. Joint angles that do not have a specified range are recorded if the measured values deviate by more than ten degrees from zero. The shoulder is considered abducted if the angle exceeds 60 degrees.

To calculate the joint torques, the external loads moved by the workers and the kinematic data of all body segments acting on the joint are required as input data. The masses of the body segments are standardised on the basis of the individual body weight according to Winter (1990). Each body segment is assumed to be cylindrical and the centre of mass is assumed to be central.

With the help of the Varignon's theorem, the joint torque can be calculated from the input data and classified using limit values for the assessment. The quasi-static biomechanical analysis of the individual joint torques allows a risk estimation of suffering MSDs. The German Social Accident Insurance (DGUV 2015) defines the torque limit values for the lower lumbar spine assessment (L5/S1-torque) and employs a traffic light system as follows:

- 0 – 40 Nm; green area; everything is ok; no need for action
- 40 – 80 Nm; yellow area; slightly increased joint torques; measures for people with restriction might be necessary
- 80 – 135 Nm; orange area; increased joint torques; need for action
- > 135 Nm; red area; strongly increased joint torques; peak load must be reduced by counter measures

The following assumptions were made for the calculation of joint torques:

- The process is regarded as quasi-static.
- Weights are recorded from 3 kg and divided into weight classes (3 - 5 kg, 5 - 10 kg, 10 - 15 kg, … , > 40 kg). The torques are calculated rounding to the upper limit.
- The load acts in the centre of the hand.
- When handling loads with both hands, 100% of the load acts on each shoulder, as it is not possible to assess the force distribution from the outside. In the torque calculation for the lower lumbar spine, the load is distributed 50% to each hand.
- Body segments are assumed to be cylindrical with a central centre of gravity. Their weights are derived from standard percentages (Winter 1990).

5.2. Physical strain

After the physical stress assessment to identify the load on all workers, a physical strain assessment is performed to evaluate the effects on the individual worker and his or her capabilities. As described in section 4.1, the ability to move is determined using standard exercises with two-dimensional movement execution. In order to establish comparability between the complex movements occurring in the process and joint mobility, all movements are transformed into the same planes from the movement exercise. For example, a complex movement of the shoulder joint is divided into shoulder flexion/extension and shoulder abduction/adduction. The software calculates the percentage utilisation of joint mobility as a characteristic value.

In order to determine the strain on the load-bearing capacity, the limit values for the joint torque evaluation are reduced if the worker's hand strength is significantly low. The grip strength of each hand influences the limit value of the respective shoulder torque and the minimum grip strength affects the limit value for the lower lumbar spine torque. The limit values are not increased if a high grip strength is measured.

5.3. Application of the workplace analysis in the LAS

With the help of the above-mentioned analyses, the stress and strain at the workplace can be determined and discussed with the employee. A DHM is used for visualisation. Here, twists in the spine and joint movements that are otherwise hidden by clothing can be easily recognised. In addition, the software allows camera movement in 3D space, which means that there is no occlusion and body postures can be viewed from any angle.

Figure 4 shows an exemplary posture to which the following section refers. In this example, the worker handles a weight of 15 kg with both hands. In addition to the shown DHM and the traffic light system for the torque assessment, the strain on the ability to move and RULA-scores are visualised. In order to identify ergonomically critical points in the work process, work steps with high RULA values, high joint torques and/or high percentage utilisation of one or more joint angles are automatically highlighted. In the following, only measures for ergonomic behavioural prevention are discussed. In industrial use, it should be checked for each posture whether an organisational preventive measure in the form of a workplace improvement would be more useful.

Characteristic Values
RULA Score: 7 (left & right)
Spine[1] flexion: 59° (78% of the ROM)
L5/S1-torque: 158 Nm

[1]Thoracic and lumbar spine

Reference Values for Joint Torques (DGUV 2015)	
L5/S1:	Shoulder:
0 – 40 Nm	0 – 40 Nm
40 – 80 Nm	40 – 80 Nm
80 – 135 Nm	80 – 120 Nm
> 135 Nm	> 120 Nm

Figure 4: Exemplary posture while handling 15 kg

Workplace-induced stress

When considering workplace-induced stress, the RULA values and the driving factors are considered first. In the example, the RULA results in the maximum risk value for the left and right halves of the body. The driving factors are the body posture, i.e. the posture of the cervical spine and the upper body, and the high external weight. From this observation, it can already be deduced as a first behavioural preventive measure that the worker should lift loads that are placed close to the ground with his or her legs instead of the back.

Subsequently, the joint torques are considered and evaluated with the global limit values from section 5.1. The load on the lower lumbar spine supports the results of the RULA and underlines the importance of posture correction. In the red zone, damage to the musculoskeletal system can already occur due to short-term peak loads, for example in the form of a herniated disc. The aim of this observation is to increase the employee awareness to the fact that even light weights in combination with non-ergonomic postures lead to a high load on the body. This should create awareness to pay attention to one's movement even with supposedly light weights and to use provided aids, such as a crane for load handling. The shoulder torques are within an acceptable range, with a slightly increased joint torque for the left shoulder.

Workplace-induced strain

In contrast to stress, which describes the external effects on people, by loads to be moved and the design and equipment of the workplace, strain is described as the reaction of people to such stresses. The degree of stress is strongly dependent on individual prerequisites, which can be determined by means of the capability analysis described above.

First, the stress on the joint mobility is considered. In the present example, none of the joints considered are close to their maximum ROM. However, it should be noted that the flexion of the thoracic and lumbar spine is already at 78% capacity. Since the work step is not a long-lasting movement, no behavioural preventive measure can be derived from this. In addition to adapting the movement sequence, measures to increase mobility, e.g. in the form of sports or stretching exercises, may be recommended if the strain was greater.

In the last step, the joint torques are considered again, with the difference that the limit values for the evaluation of the joint torques are now reduced depending on the hand strength measurement. If the worker had a grip strength measurement significantly below average for the left hand, lowering the limit values of the left shoulder torque leads to a new evaluation and a classification of the joint torque in the orange area (see section 5.1). In this case, exercises to strengthen the upper body would be recommended. The double consideration of joint torques aims at a higher awareness on the part of the worker that his or her individual capabilities have a significant influence on the effect of workplace stress and that low overall muscle strength requires an expanded health awareness at the workplace.

Following the analysis of each work step, the workplace analysis can be repeated to demonstrate the effect of immediate measures such as improved movement execution. Individual movements should be performed again directly after the measures have been derived and before the next critical work step in order to achieve a high learning effect. The learning success can be evaluated by repeating the assessment regularly (e.g. every year). If the same work process is analysed, the characteristic values of the initial recording can be compared with the characteristic values of the repeated recording to quantify the effect of the LAS on the workers' behaviour.

The workplace analysis was carried out with the same test persons as in section 4.3 at multiple assembly and logistics workplaces. The stress and strain on the employees was determined, but a review of the measures derived in the learning assistance system has not yet been carried out.

6. Summary and Outlook

This paper shows how a low-effort capability analysis can be carried out with 14 movement exercises and a grip strength measurement to create an ergonomic capability profile for production workers. With a workplace analysis, which includes the RULA and a consideration of joint torques, the workplace-induced stress is determined. A combination of the two analyses leads to workplace-induced strain on the worker. Through the low-effort recording with a motion capture system and through an automated evaluation, the results can be used in a LAS for ergonomic behavioural prevention.

The direct individualised ergonomic evaluation is visualised with the help of DHMs. This makes it possible to identify non-ergonomic movements at the workplace, to improve them and to review the measure. In addition, measures can be recommended to the employee to increase his or her mobility and strength capabilities in order to avoid the overload of individual capabilities and to enable safe work. The learning success can be monitored by repeating the assessment in certain intervals.

The individual elements of the LAS have already been tested in an industrial environment, but the concept has yet to be implemented as a whole over a longer period of time. Also, it needs to be checked whether the hand strength is sufficient as an indicator of the load-bearing capacity. Although the correlation of hand strength with total muscle strength indicates the legitimacy of the assumption, a clinical study should be carried out on the correlation between hand strength and the limit values of the joint torques.

Acknowledgements

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Change in competence requirements due to the pandemic-related change in work organisation

Schmauder Martin, Ott Gritt, Montenegro Hörder, Elena

1. Initial situation

As the worst global crisis since World War II, the COVID-19 pandemic is affecting public health and causing unprecedented damage to economies and labour markets (ILO Monitor, 2020, p. 2). The BMBF-funded research project "COVID 19 LL Lessons Learned" aims to address the work organisation challenges that have arisen because of the changed working conditions. Through a systematic analysis, successful solutions and measures to ensure the ability of companies and organisations to work are to be identified, which have crystallised in three different German federal states. The regions of Bavaria (TU Munich), North Rhine-Westphalia (RWTH Aachen) and Saxony (TU Dresden) were considered as examples.

Already a few weeks after the outbreak of the pandemic[1], measures based on regulations were taken by the company/organisation managements to slow down the course and spread of the virus. Contact restrictions, also called social or physical distancing, and home office regulations were demanded and implemented in the official environment as effective measures (Alipour et al., 2020, p. 34). The topic of home office and the associated change in work processes came into the focus of labour science at the same time and plays a central role in this paper.

To analyse the change processes, a total of 52 expert interviews were conducted in companies and organisations from different sectors.

This article is dedicated exclusively to the measures and procedures of the Saxon service sector, which were identified and based on nine interviews with experts.

1 Restrictions from March 2020 by the Federal Ministry of Health (2021)

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2. Objective

The aim of the COVID19-LL project was to identify the problems that, due to the pandemic, companies and organisations are confronted with. In addition, the new ways of working learned through the change processes were analysed in terms of their impact. The aim was to find out whether the innovative and digitally supported forms of work initiated by the pandemic had a positive impact on the working world in medium and long term. Another point of investigation was the change in competence requirements due to the pandemic-related change in work organisation.

For the empirical analysis, the MTO approach (Figure 2) was chosen as a starting point and decided research questions (Figure 3) were developed. The systematic and methodological approach is shown in Figure 1. Based on the analysis and evaluation of the material, recommendations for action could be generated. Finally, these were placed in the context of occupational science in a critical discourse and further fields of research were identified.

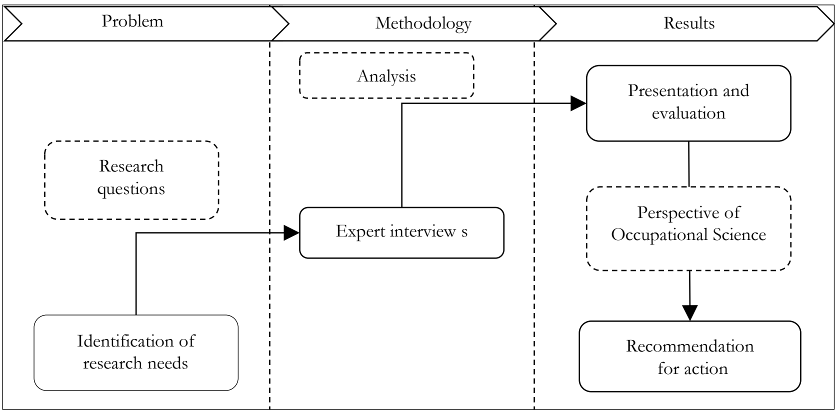

Figure 1: Methodological approach (own representation)

2.1. Problem

Due to the lack of digitalisation in large parts of the service sector (Alipour et al., 2020; Heuermann et al., 2018; Statista, 2021) the pandemic catalysed the digitalisation process considerably. The insufficient technical equipment, especially networking, lack of digital skills and the sudden shift of the place of work away from the workplace posed major challenges for companies.
To date, there is a lack of theoretical and empirical findings on the evaluation of the implemented flexible working models, the advancing digitalisation and the technical equipment in companies in the Saxon tertiary sector.

Using the data material, the status quo ante pandemic, the status quo and the status quo post pandemic were determined and analysed by means of research questions.

Using the process model "Human-Technology-Organisation", which is shown in Figure 2, the interdependence and influence of the three factors becomes clear, which had to be particularly considered in this project. Due to the changed external conditions, the work technologies, the individual working methods of the employees and the process organisation developed furtherThe interaction of the three factors within the work organisation during the implementation of the measures could not be analysed due to the time restrictions. However, it will be derived in chapter 5basis of the further results how and whether the process model has changed sustainably.

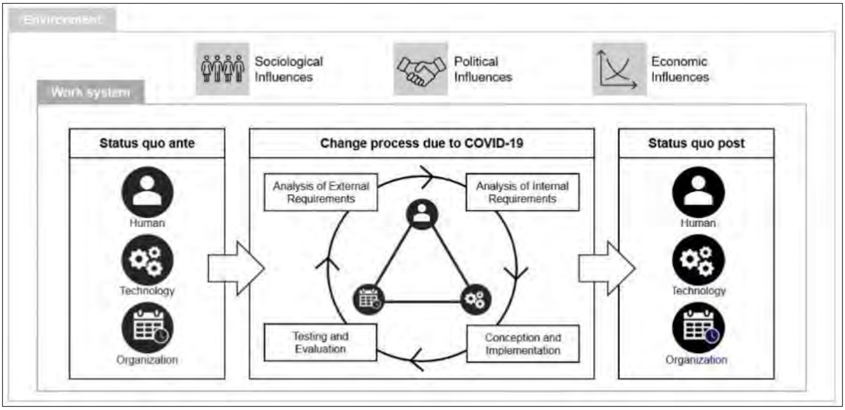

Figure 2: MTO process model of the COVID19-LL project
(own representation)

2.2. Research questions and hypotheses

This paper focuses on four problem areas that are closely related to the crisis and are particularly relevant for the service sector: the aggravated customer contact in times of "social and physical distancing" (Koren & Pető, 2020), the (lack of) digitalisation in the service sector (Heuermann et al., 2018), the securing of results of work processes in home offices (Landes et al., 2020) and the subjectively perceived insecurity of employees (Grömling & Matthes, 2019). The research questions, listed in Figure 3, consider this tense relationship of the tertiary sector holistically. The fifth research question aims at the pandemic-related improvements and bundles the results into further recommendations for action.

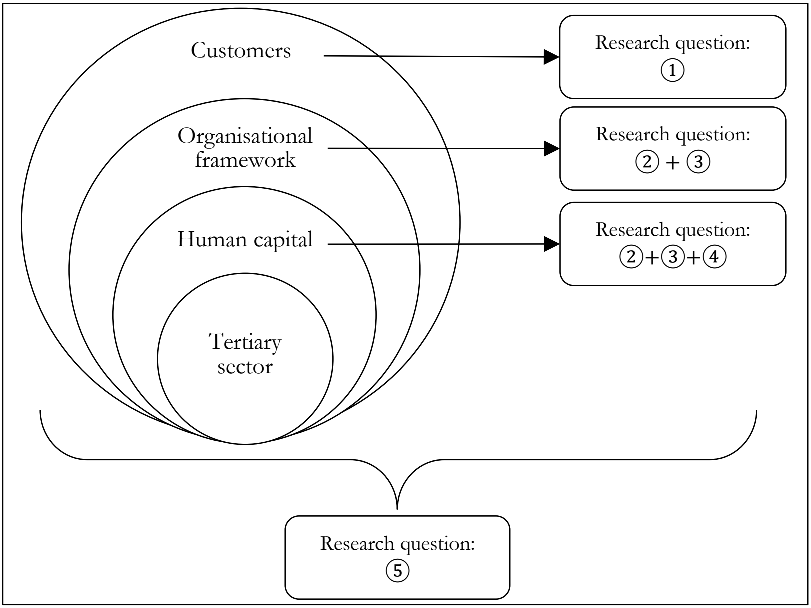

Figure 3: Derivation of the research questions (own representation)

The research questions and hypotheses are explained in the following and subsequently answered after the methodology approach.

1. How can good customer care in the service sector be ensured despite "social and physical distancing"?

   Hypothesis: Through social and physical distancing, the personal contact between customer and employee deteriorates considerably.

2. What technical equipment and know-how must have been available before the pandemic in order to successfully master the rapid implementation of measures?

   Hypothesis: The rapid switch from face-to-face work to home office can only work with already existing mobile devices, data protection concepts and digital competences of the employees.

3. What are the possibilities and challenges of performance monitoring/assurance of results when working in home office?

   Hypothesis: Performance monitoring and securing results in home office require the teaching of competences for "leading from a distance" as a skill for managers.

4. What subjectively perceived concerns and uncertainties do employees feel during the pandemic and to what extent does a manager have an influence on this?

   Hypothesis: The manager can directly influence the concerns and insecurities of his/her employees with the help of targeted communication.

5. What improvements have occurred as a result of the measures and how can these be carried over into a post-pandemic period?

   Hypothesis: The improvements that have occurred imply long-term changes in the overall organisation of work.

3. Methodical approach

The project as a whole aimed to investigate and describe the complexity of pandemic-related changes as comprehensively as possible. Therefore, the focus was less on the representativeness of the study than on identifying as many different approaches as possible.

Due to the theoretical considerations that preceded the data collection, the sampling was based on the criteria-driven and conscious selection of the target group. (Akremi, 2014, p. 273). Various characteristics were worked out according to which people were eligible for the sample and which enabled the targeted contacting of people from the service sector. The criteria and characteristics were, on the one hand, the location in the service sector according to the classification of economic sectors (2008), the geographical location in Saxony and the direct impact of the pandemic on everyday working life. The interest was directed at both managers and employees without personnel responsibility to show the respective perspectives of both groups of people. These criteria for selecting the sample legitimised the classification of the participants as experts.

Out of a total of 92 interview requests, nine expert interviews could be conducted. Due to a lack of capacity, most of the requests were rejected. The nursing sector, for example, received alone 24 interview requests, which were not accepted because of heavy overload, which was due to the massive effects of the pandemic.

Due to the COVID 19 pandemic, seven interviews were conducted by telephone and two interviews by web-based communication medium. Despite the omission of the visual component in telephone interviews, the advantages of the rapid accessibility of the participants and the low time, organisational and monetary expenditure for conducting the interviews outweighed the disadvantages. Furthermore, the accessibility of groups of people from different social, professional and hierarchical strata by telephone was better than personal contact.

On average, the interviews lasted about 55 minutes and were transcribed with the help of the QDA software f4transcript and according to the transcription rules of Kuckartz and Rädiker (2019, S. 449) and analysed with the f4analysis program. In the end, the expert interviews were conducted in three areas of the service sector: public administration, social services and social insurance. In order to guarantee the anonymity of the interviewees, the geographical location cannot be assigned to the respective institutions and the interviewees. They are located in the districts and cities of Bautzen, Chemnitz, Dresden, Leipzig and Reichenbach. Among the interviewees were seven managers with personnel responsibility, including district councillors, mayors, a head of department and a state representative of a health insurance company. Two employees who did not have personnel responsibility worked as consultants. Seven interviewees were male two female. The distribution of persons per service area and personnel responsibility can be seen in Figure 4.

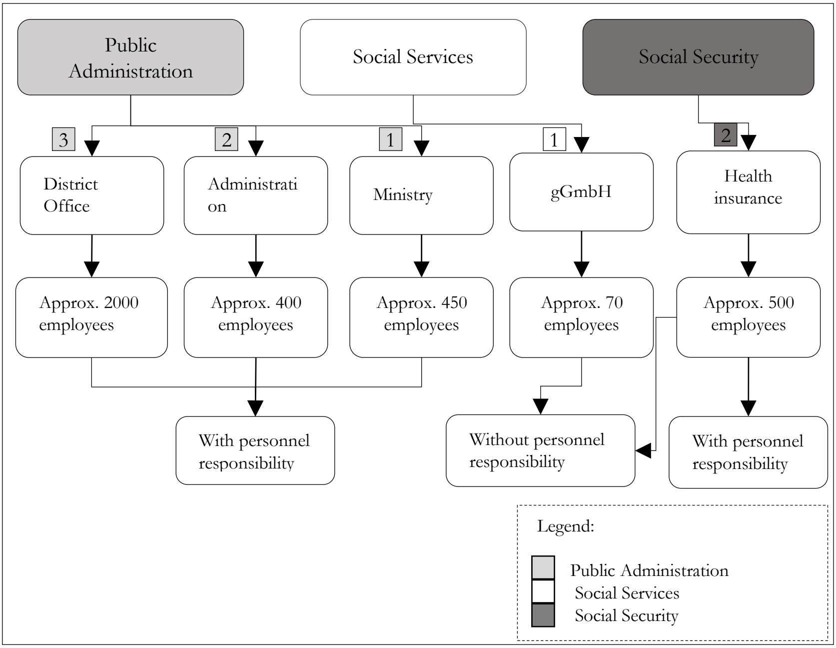

Figure 4: Typification and specification of the interviewees (own representation)

By analysing the expert interviews using content-structuring qualitative content analysis according to Mayring (2010), it was possible to achieve the goal of the survey instrument, namely intersubjective comprehensibility and understanding of the experts' subjective constructions of reality (Misoch, 2019, p. 3). After the material had been processed, it could be systematised through inductive and deductive category formation before it was evaluated on the basis of the research questions. Taking into account the research questions and the questions of the interview guide, main categories were formed. In the next step, corresponding subcategories were assigned to the main categories step by step (Niederberger & Ruddat, 2012, p. 8). This followed the exact provisions of the developed category definitions and coding rules (Fenzl & Mayring, 2017, p. 637), which were summarised, modified or eliminated in feedback loops after a conscientious review (Mayring, 2010, p. 603), so that arbitrary category formation was excluded. In order to answer the research questions and to form categories in a meaningful way, an interview guideline was developed, through which inductive category formation in particular was made possible. Table 1 shows an excerpt of the interview guide for the first research question. For each research question, the status quo ante pandemic, the changes in work organisation and the status quo were asked in order to obtain standardised and differentiated results for each research question.

Research question 1: Customer contact with social/physical distancing	
Guiding questions (opening, narrative-generating questions)	Memo for follow-up questions (Control questions)
1) Please describe your administration / company to me?	Your person, workforce, qualifications…
2) Please describe how you worked before the pandemic?	With customers? Stakeholders?
3) What central effects have you been able to feel?	General, specific?
4) What measures have been taken to respond to the impact of the pandemic?	When did which changes occur?
5) How did customer contact take place before/during the pandemic?	Was there any feedback on this?
6) How was physical distancing implemented?	On what premise?
7) What permanent changes will there be in this regard?	Are there any requests from employees/leaders?
8) What does the future work with clients look like?	Additions?

Table 1: Extract from the interview guide (own representation)

4. Results

All interviewees confirmed that the COVID 19 pandemic has significantly changed work in the factories. The need to reduce physical contact is the main driver for changes in working practices. In the majority of cases, this has led to far-reaching hygiene concepts, team building with spatial and/or temporal separation and a drastic reduction in business trips.

The greatest changes and drastic measures were the comprehensive introduction of mobile working. In the survey period November 2020 - February 2021, home office work was carried out in eight out of nine companies. Although home office is legally considered mobile work, it must be seen as quasi-stationary work from the perspective of labour science. It could not be conclusively determined whether the companies investigated offered mobile working or home office. Neither could it be determined whether the ergonomic conditions outside the office could guarantee optimal working conditions. Possible consequences in health management or of a financial nature are expected in long term.

In addition to the introduction of mobile working, the interviews conducted revealed an enormous digitalisation push within the companies. The technical equipment and the technical/digital know-how improved considerably in all interviewees. The initial supply bottlenecks of technical equipment were not a major problem, as employees were willing to use their private devices. The situation was different when it came to data protection. In order to ensure the ability to work, in seven cases employees had to take paper files and personal data home for processing, which does not comply with the valid rules of data protection. One person had to rely on the assistance of colleagues on site who scanned documents to send them by email. To ensure data protection, legal principles had to be implemented in the first weeks of the home office. The switching of tokens by the IT departments of the companies helped to ensure data protection-compliant work. The two companies that were already using mobile working before the pandemic were sufficiently digitised and were already working in a data protection-compliant manner, so there was no need for action.

Figure 5 summarises the main results. These lead to further recommendations for action for the respective companies, which were developed from a work organisation perspective and are explained in detail below.

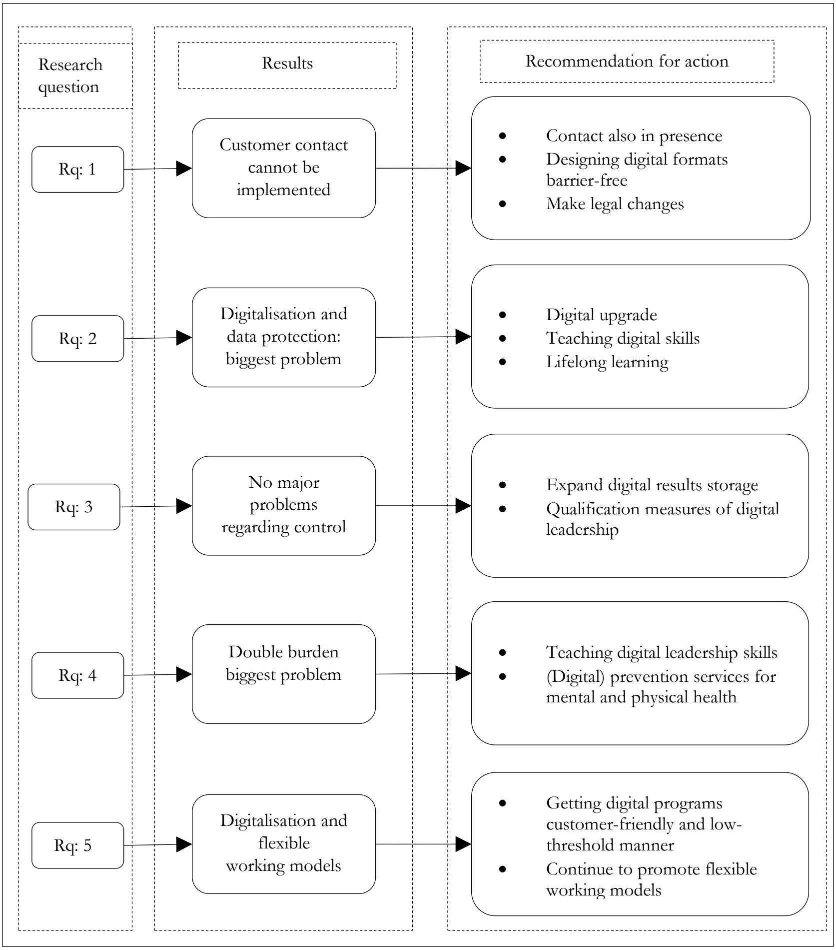

Figure 5: Summary of the results (own representation)

On the first research question: Customer contact in physical distancing

Not all groups of people (clients) had access to administrative services that took place digitally and without personal contact due to mobile work. Three administrations named this as the main problem of customer contact. The negatively affected clients can include people with disabilities, without sufficient German knowledge or people who are educationally disadvantaged. The hypothesis for the first research question can therefore only be partially confirmed. Although a large part of the population perceives digital formats positively and sees them as an improvement despite physical distancing, there is a small part of society that is dependent on physical encounters. As a consequence, physical contact should be maintained for those who cannot participate through digital formats due to their disposition. Another possible course of action is to make administrative services barrier-free. For this purpose, this group of people should be included in the creation of digital formats.

On the second research question: Technical equipment and know-how

The importance of technical equipment could be answered comprehensively. Six of the nine people interviewed stated that they had been insufficiently digitally equipped before the pandemic. The restructuring caused by the SARS-CoV-2 occupational health and safety standard hit the industry with full force. This meant that an orderly, phased introduction of home office was not possible. For example, this meant that mobile working, which was implemented at short notice, initially meant that there was no access to the company network, which was the case for three interviewees. Many employees had to use their private computers, which hindered work and posed an additional high security risk. New software programmes for digital communication had to be introduced overnight. This in turn put everyone's technical know-how to the test, which was described by five people as "highly variable". One person linked the lack of technical affinity within their team to the advancing age of the staff. The actual implementation of technical changes depended not only on age but also on the willingness of the employees. For this research question, too, the hypothesis can only be partially confirmed. It was not the already existing end devices that were decisive for a rapid changeover, as private end devices could be used. However, digital skills were needed to use the new software, such as virtual communication programmes, quickly and securely. One recommendation for action that can be derived from this is the establishment of lifelong work-integrated learning. Digital skills can be developed through the teaching of digital competences, which are a prerequisite for the rapid introduction and use of new software and new communication platforms.

On the third research question: performance monitoring and securing results

Surprisingly, no major difficulties were found with regard to monitoring performance and securing results in the home office. Without exception, all those interviewed stated that they trusted their employees or were trusted by their respective managers. The process of change from face-to-face work, to work away from the workplace was quickly made possible through relationships of trust within the companies, so that the work done was recorded in transparent and digital programmes and made quantifiable. Communication between employees and managers on results-oriented and self-directed work was positively received by all persons. All interviewed managers supported the trusting relationship with employees and were confident that they would continue to work with each other at this level in the future. However, two interviewees noted that leadership had changed. Some managers had insufficient digital leadership skills. Thus, the third research question identifies the teaching of digital leadership skills as a need for qualification, which is supported by the hypothesis of this research question.

On the fourth research question: uncertainties and concerns

The fourth research question related to employees' insecurities and concerns and how managers influence them. In all interviews, the double burden of childcare and working from home at the same time was mentioned. This concern particularly affected those who were not entitled to emergency care for their children due to their job. To overcome the challenge of the double burden, the implementation of individual and accommodating solutions was mentioned by all interviewees. Partial leave, taking leave, accumulating less hours and reducing working hours for a certain period of time were pragmatic, unbureaucratic and quick solutions and helped to reduce the burden. This approach was rewarded by the employees. As one manager put it: "We took a leap of faith, which was repaid to us by the staff with double and triple interest. As the quotation makes clear, it could be noted that the empathy of the manager to support the employees was received in a positive and appreciative way. The subjective assessments in Figure 6, at least for the internal climate, show this. Despite the assumption of a deterioration due to the prevailing stress, the opposite is the case. Cooperation has deteriorated for four people due to the physical distance and the discontinuation of informal conversations. This was mainly caused by the video conferences that were introduced. For three people, on the other hand, cooperation improved due to digital communication. They were able to concentrate better on their own work due to the elimination of informal conversations and were less distracted. In addition, one manager allowed 10 minutes for informal conversations in all video conferences in order to replace the "hallway conversations" that had been eliminated. No trend is discernible in the assessment of job satisfaction.

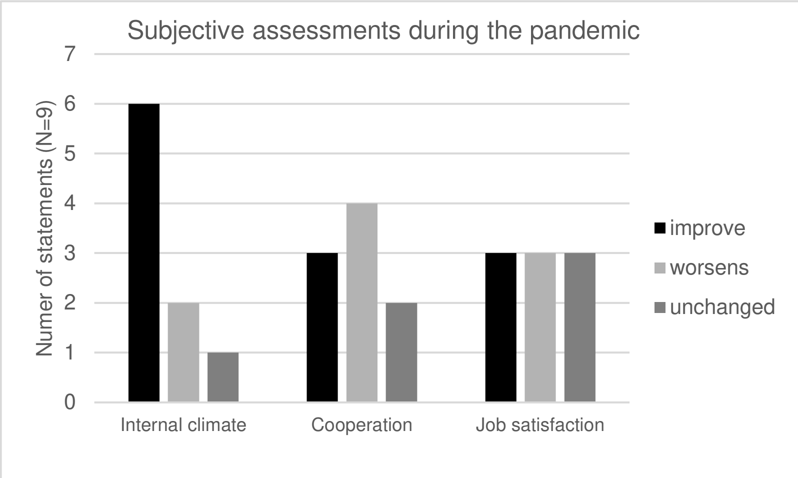

Figure 6: Interviewees' assessments of the change in internal climate, cooperation and job satisfaction during the pandemic (own representation)

The hypothesis that managers have a direct influence on the concerns and uncertainties of their employees with the help of targeted communication can be confirmed at this point.

On the fifth research question: Improvements

The fifth research question deals with the resulting improvements. These consist of the advanced digitalisation with the new work opportunities. This is accompanied by the expansion of flexible working models and the reduction of business trips. Due to the positively perceived change in the established communication processes with superiors, all restructuring within the work organisation could be implemented quickly. The own increased flexibility, as shown in Figur 7, leads to an overall flexibilisation of the work organisation. Through digitalisation and the improvement of digital communication, increased productivity was recorded by four people, which underlines the relevance of digitalisation.

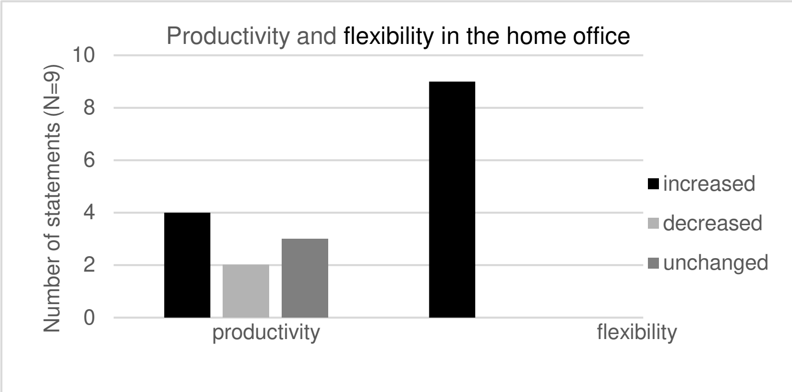

Figure 7 : Interviewees' statements on productivity and flexibility during the pandemic (own representation)

The hypothesis that organisations need to change in the long term is confirmed by the fifth research question and further elaborated in chapter 5

5. Conclusion

It can be deduced from the research results that almost all of the interviewed companies and organisations are in a phase of change. More than a year after the outbreak of the pandemic, most of the interviewees have found a way to deal with the new situation in the best possible way. Experiences have been gained and lessons learned, which are now to be used in the long term to improve work processes and competences. Nevertheless, appropriate framework conditions still need to be created to consolidate the changes.

For example, Figure shows the benefits of mobile working, such as increased flexibility, which has led to an improvement in group dynamics. Another achievement is the increase of innovations within the work organisation, such as holding virtual job interviews, which not only saves time and monetary resources and benefits the work-life balance, but also has a positive impact on environmental sustainability.

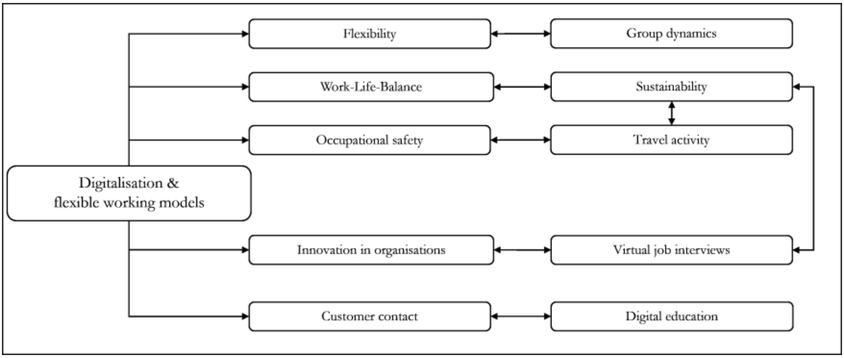

Figure 8: Improvements brought about by the pandemic
(own representation)

At the same time, the disadvantages, such as the danger of increased work volume, increased pressure to perform, unclear separation of work and private life, should be minimised through results-oriented communication. (Stowasser et al., 2019, p. 5) . To this end, it is important to give greater importance to preventive health protection than is currently the case and to pursue this proactively. In addition to creating optimal ergonomic conditions away from the workplace, emerging psychological impairments such as symptoms of stress, overwork or underwork must also be recognised from a distance. With the help of counselling and training services, these potential causes of illness can be addressed and eliminated. Even though the health risk in the home office was only recognised by one interviewee, this recommendation for action should apply across all sectors.The human resource as the most important factor in the service industry must be the focus for every business. At this point, the reference back to the MTO process model can be made. Despite the equal interaction of people, technology and organisation, people will be the ones to decide on the speed of progress. The process model will change in the future so that the three factors will be even more closely interlinked. As a result, digital opportunities and physical contact will have to be combined in a meaningful way.

Another finding of the studies is the importance of a trusting working relationship. In addition to increased autonomy and self-direction, this leads to an economic promise of success and should be (Breisig, 2020, p. 190) and should be expanded beyond the service sector. Seven interviewees confirmed the positive influence on the internal climate, which was created by the trusting working relationship.The recommendations for action for further training measures in the areas of trust-based digital leadership and management competences for executives build on this. The keyword of lifelong learning applies here not only to employees who are trying to remain employable, but also, if not especially, to managers. Even though these competence requirements were only mentioned by three people, from the research point of view they are an elementary component of good employee management, which has been given a current dynamic and importance by the COVID-19 pandemic. A management that is capable of learning is very likely to get through the volatile period of the pandemic more safely, to outgrow itself and thus to achieve a longer-term improved resistance to crises.

Efficient work design that is free of impairments and conducive to learning and personal development, combined with contemporary digitalisation, is the prerequisite for building crisis resilience. This is where the competence requirements of today differ from those of recent years. The tertiary sector must accept these new conditions in order to increase not only competitiveness but also employee satisfaction, which is essential for the future world of work. (Mustapha, 2021, p. 7) .

In summary, it should be noted that in addition to the obvious competence requirements, those were also identified that were hardly mentioned in the interviews but are extremely relevant from an occupational science perspective. The advancement of digitalisation, data protection and the sensitisation for trust-based working relationships could already be recognised as opportunities for companies. Now it is a matter of making visible the subliminal need for competence, such as leadership from a distance with the demand for a healthy, satisfied and innovative working relationship. This will form the basis for meeting the new demands of managers and employees on the world of work with suitable offers. The comprehensive changes within work organisations were forced by the pandemic. Now it is a matter of using them not only locally and regionally, but also globally and in the long term, and of understanding them as opportunities.

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A learning factory approach on machine learning in production companies

How a learning factory approach can help to increase the understanding of the application of machine learning on production planning and control tasks.

Alexander Rokoss, Kathrin Kramer, Matthias Schmidt

1. Introduction

Technological progress and increasing digitalization offer many opportunities to production companies, but also continuously confront them with new challenges. On the one hand, automation of processes is progressing in manufacturing and upcoming technical support systems, such as automated guided vehicles, are leading to significant changes in workflows. On the other hand, large amounts of work within companies are still done by humans. This is also the case with production data processing. Although in many enterprises data is already collected and sorted automatically, the final evaluation of this data and especially decision-making is often done manually. Especially decisions that cannot be handled on the basis of conditional programming are usually made by humans.

The use of artificial intelligence (AI), in particular the use of machine learning (ML) algorithms, represents a promising approach to support the automation of complex decisions (Buxmann/Schmidt 2019; Kuhn/Johnson 2013). A steep increase of scientific publications in recent years (Schmidt et al. 2020) evidences the trend that more and more companies and institutions are dealing with the utilization of ML in production planning and control (PPC). However, many of the publications originate from a purely scientific environment, so a widespread use in companies is not visible yet (Usuga Cadavid et al. 2020). Rammer et al. state in their report that with 17,500 analyzed companies, 5.8% are already using AI in products, services, or internal processes. At the same time, the report indicates that 43% of the overall 22,500 AI-related vacant jobs at the time of the survey, could not be staffed (Rammer et al. 2020). The resulting massive shortage of skilled workers in the field of AI must be addressed in the short- and mid-term by training and educating existing employees in production companies. A promising approach to build up competencies within production companies is the use of learning factories as a knowledge transfer enabler. Learning factories offer participants the opportunity

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to apply new methods in a realistic environment without the risk of negative consequences on live production processes (Abele et al. 2017). In this context, the influences of applied methods can be directly experienced without time delay, resulting in better learning results compared to conventional full-frontal teaching methods (Sackey et al. 2017). Supplementary, a gamification of learning content eases the learning process thanks to facilitating a "learning by doing" mentality (Keepers et al. 2020).

As mentioned above, professionals in PPC daily face the task of decision making on complex issues. The decisions are often based on experiences, sometimes supplemented by indicators generated from existing data. As early as 1992, Yang et al. proposed the use of intelligent systems for planning production processes (Yang et al. 1992). To be able to make decisions more reliable and to preserve the knowledge of long-time employees, intelligent support systems using ML methods are needed. To develop and operate such systems, professionals need specific training that enable them to acquire the necessary skills and competencies. Literature shows that the focus of most learning factories, operated at corporate or university level, is on lean management and demonstrating digitalization technologies to support lean manufacturing (Martinez et al. 2020). Although ML approaches have already been implemented, PPC tasks are very rarely addressed (Martinez et al. 2020). Grounded on their relevance for meeting contracted delivery dates with the customer, one central component of the planning process in PPC is the determination of lead times (LT). A possible procedure for the application of ML methods is the use of a data mining process like the Cross Industry Standard Process for Data Mining (CRISP-DM) (Chapman et al. 2000; Usuga Cadavid et al. 2020). The combination of the general approach of CRISP-DM combined with the specific field of ML-supported LT prediction in a learning factory environment has not yet been deeply investigated. A learning factory training on the use of CRISP-DM and the utilization of ML to determine production LT in a job shop can help to improve the knowledge transfer on developing ML applications in production environments.

Henceforward, this book chapter describes a learning factory training on the utilization of ML approaches in PPC. A brief introduction into learning factories and ML in PPC is followed by the design methodology for the learning factory training. Afterwards necessary competencies are identified, leading into the conception of the training phases. Lastly, the conclusions are summarized, and future research possibilities are outlined.

2. Learning factories

Learning factories allow participants to actively engage in the implementation and improvement of production processes in a realistic environment. One of the key advantages is the direct response of the production system as a result of decisions made by the participants without time delay (Sackey et al. 2017). Depending on the didactic purpose, learning factories teach a specific subfield of production. To equip learners with tools for immediate reaction, the tasks to be solved always derive from problems occurring in real world production systems (Abele et al. 2019). This results in participants developing professional competencies while avoiding to harm the real world production environment (Abel et al. 2013). Another major advantage of learning factories is the superior performance in generating knowledge compared to traditional teaching (Cachay et al. 2012). Physically experiencing a learning process promises a significantly deeper anchoring of the new information as well as more joy in the learning process itself. The lack of consequences of errors for crucial processes in the live production environment clearly encourages curiosity and the motivation to experiment in learning factories (Deslauriers et al. 2011; Haghighi et al. 2014).

The majority of existing learning factories currently address topics of lean management as well as how to deal with digital transformation technologies (Abele et al. 2015; Sackey et al. 2017; Veza et al. 2017). In a recently published study Martinez et al. show the rapid increase in publications dealing with learning factories since 2015 (Martinez et al. 2020). Lately ML methods have already been implemented in learning factories addressing predictive maintenance (Daniyan et al. 2020), quality control (Oberc et al. 2020), activity and position recognition (Hofmann et al. 2020; Zhang et al. 2020) or process mining on end-to-end order processing (Schuh et al. 2020). For the training presented here products and the environment of the learning factory already existing at the Leuphana University of Lüneburg are used, allowing access to the ecosystem data and IT systems.

3. Machine learning in production planning and control

As most tasks in PPC are depending on predictions in complex environments, the selection between different actions turns out to be difficult (Nyhuis/Wiendahl 2006; Wiendahl 2014). ML approaches could help to solve those problems. Arthur Samuel (1959) defines ML as the field of study in which not every step is programmed to the computer by humans. Instead computers learn independently by developing rules (Chollet 2018). Using labeled training datasets, the rules mentioned are determined and applied to an unknown dataset.

Since 2016 a steady growth in publications related to ML can be observed (Döbel et al. 2018). A bibliometric analysis by Schmidt et al. (2020) shows that the distribution of ML's potential across main PPC tasks (Schäfers/Schmidt 2015) in scientific publications is extremely heterogeneous and varies from no publication to more than one third of all publications classified. One of the main focus areas of publications classified by Schmidt et al. were LT scheduling and scheduling in general, whereas in previous years the focus was on sequencing. This trend could be explained either by the large share of already existing approaches (e.g. case studies by Gyulai et al. 2018; Lingitz et al. 2018) or by the development progress in the ML area, resulting in easier applicability to problems that are more complex. As publications in recent years have increasingly focused on scheduling and LT determination, the following section takes a deeper look into the principles of LT determination using regression models.

4. Methodology for the design of the learning factory training

The desired outcome at the end of the learning factory training is the knowledge on how ML methods can be used for the determination of LT for new production orders in a production environment. As a data mining process like CRISP-DM offers a structured procedure for handling the required data and making an accompanying documentation, it can function as the basis for the learning factory training. According to CRISP-DM, it records relevant production data, gains transparency of the processes from the data obtained and finally generates recommendations for action utilizing ML (Chapman et al. 2000). Within the learning factory training, participants will encounter the difficulty of precisely determining LT under uncertainty. On the one hand, the training guides the learners through the data collection process using available digitalization technologies. On the other hand, it encourages participants to setup a ML application themselves to determine LT. By going through CRISP-DM stepwise, participants are enabled to setup a ML application on LT determination that is trained and tested with a dataset originating from a real job shop production site. The methodology shown in Figure 1 is used to develop the required training phases.

The conceptual design of the learning factory training begins with the definition of teaching objectives. Next, associated competencies need to be identified. Three steps are involved in identifying the competencies. First, the underlying theory on CRISP-DM as well as an example of ML methods used for LT determination in practice is analyzed regarding the definition of teaching objectives. Second, necessary competencies on setting up CRISP-DM using ML methods are extracted from the given theory. In a third step, findings are then compared with Danyluk/Bucks analysis of AI competencies on data science and Long/Magerkos 2020 paper on AI literacy. The analyzed competencies are recorded using the matrix structure for evaluating technical-methodical competencies according to Abel et al. (2013). Next, a fictitious scenario is developed, that forces learners to deal with the determination of LT within the simplified job shop environment used in the learning factory training. Lastly, the training is split into phases that teach specific groups of competencies. In conclusion, the learning results can then be evaluated in regards to the set teaching objectives, which are presented in the next section.

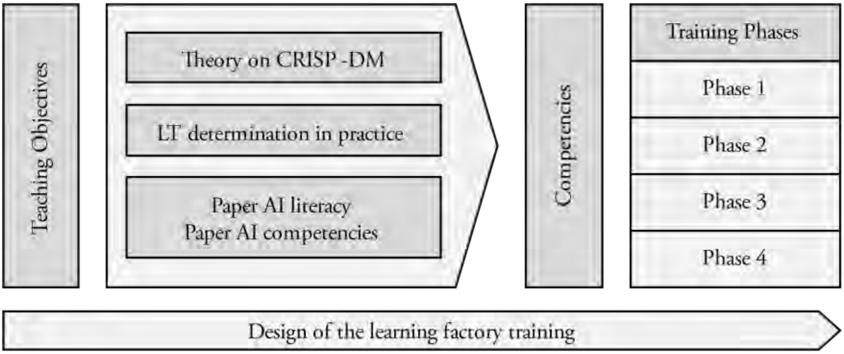

Figure 1: Methodology on the design of the learning factory training

5. Teaching objectives

According to the Learning Factory Curriculum Guide by Tisch et al. (2013), the first step in creating a new learning factory training is the determination of teaching objectives. Overall, the new training aims on teaching participants the necessary competencies to setup a data mining process according to CRISP-DM using ML approaches. Regarding CRISP-DM, the didactic objectives are the secure handling of the process steps themselves as well as understanding the impact the process itself has on the overall quality of the ML prediction models. Another key objective regarding CRISP-DM is to teach the participants the overall relevance of specific process knowledge in order to develop precise ML models.

In the field of ML, the learning factory training contains four teaching objectives. The first one is to provide participants with a comprehensive overview of the technologies and regression methods underlying the concept (A). Building on this theoretical foundation, the second teaching objective of the learning factory training is to emphasize the importance of comparing available learning models with reference to each individual case in application (B). The third teaching objective is defined by the ability of the participants to understand the respective areas of application of ML and the actions required to use it effectively and efficiently. This implies the participants to the importance of the interaction of process knowledge, precise data mining and the selection of sufficient ML processing applications (C). The fourth teaching objective is to enable the participants to independently design a ML application following the CRISP-DM using ML regression models (D).

Since the teaching objectives focus on individual participants, single or multiple quantitative indicators cannot measure the teaching objectives. Therefore, the game phases need to be designed to only allow participants to proceed within the learning factory workshop, if they fully enabled themselves to make use of the competencies taught in the previous game phase. This implies a strong connection of the success of a game phase from the participant's perspective with the achievements of the defined learning objectives from the teacher's perspective.

6. Identification of required competencies

6.1. CRISP-DM

CRISP-DM is a widely used, industry-independent standard process for data mining, which is divided into the six stages "business understanding", "data understanding", "data preparation", "modeling", "evaluation" and "deployment" (Chapman et al. 2000). It has already been applied by Lingitz et al. to the specific problem of forecasting LT (Kristoffersen et al. 2019; Lingitz et al. 2018). As a target-oriented use of ML models on real-world problems is influenced by the decisions made within the complete process – from data generation to deploying a final model – it is useful to carry out a structured data mining process to make appropriate model assumptions (Awad/Khanna 2015; Kuhn/Johnson 2013). The first phase, business understanding, contains the definition of business and data mining goals. Additionally, it analyses the current situation and defines the desired outcome of the whole process (Chapman et al. 2000). In the data understanding phase initial data are being collected, described, and the overall data quality is evaluated (Chapman et al. 2000). The data preparation phase deals with the selection of adequate data for the modelling phase and prepares the data. This is done by cleaning, adding further data or integrating further data sources as well as formatting the data (Chapman et al. 2000). The preparation phase also includes the crucial task of selecting relevant data attributes (e.g. number of workstations per order), also called features, or the creation of more suitable features (Kuhn/Johnson 2013). During the modelling phase, curated regression methods are modelled, and a generated test design evaluates the models. In the evaluation phase, the results are evaluated and follow up steps are determined regarding a potential deployment. The evaluation either leads to adjustments of the previous phase and therefore to a repetition of the modelling process or to an approval of a sufficiently performing model. If the model gets approved, the deployment phase starts, containing planning the deployment and runtime management as well as assessing the project within a project report. In the context of deployment, regular model updates are required as characteristics of manufacturing systems or processes can change (Deep/Singh 2015; Hammami et al. 2017). Because of its recursive structure, CRISP-DM underlies a continuous improvement process and thus serves a deployment more than a snapshot as a final output.

6.2. Lead time determination supported by machine learning

In practice, traditional methods for the determination of LT often react insufficiently to changing environmental influences, especially in complex production environments like job shop manufacturing. Possible environmental influences are e.g. machine breakdown or fluctuations of the production load (Ludwig/Nyhuis

1992; Wildemann et al. 2005). Traditional approaches for LT determination include methods based on estimates, historical values, logistic models and simulation (Ziarnetzky/Mönch 2016). The limitations of most of the classical methods can be explained by too simplified assumptions. Approaches such as flow degree oriented scheduling or simulation aim to overcome these limitations. However, these do not lead to a significant improvement of the planning quality in relation to the increased effort (Lödding 2016; Ludwig/Nyhuis 1992; Nyhuis/Wiendahl 2012).

According to Ludwig/ Nyhuis (1992), LT prediction contains order characterization, the processing sequence, current work in progress and the capacity situation within the production. In complex production environments, LT are influenced by many input factors. However, employees in production planning are often not fully aware of the relevant input factors and their effects (Halevi 2010; Schuh et al. 2019). To counter this, companies can utilize production data, which is often available in large quantities (Chen et al. 2014).The increased variety and quantity of data in companies can be used to evaluate data and derive insights for the planning process (Awad/Khanna 2015; Buxmann/Schmidt 2019; Ertel 2013; Gentsch 2018). However, the numerous factors influencing LT in job shop manufacturing make it difficult to master the planning process, even if all relevant data is recorded. This underpins the potential of ML in LT determination as already proven in several case studies (Gyulai et al. 2018; Lingitz et al. 2018). Table 1 presents an overview of used data, regression methods and evaluation methods of case studies in complex production environments.

All studies listed use regression methods for the ML-based determination of LT and use either simulation or real data. Overall, information such as order data, data on the system status, material or employee related data is included (Burggraf et al. 2020; Gyulai et al. 2018; Welsing et al. 2021). Since the importance of different input factors varies in the context of the respective company, industry-specific input factors are not further discussed in this chapter.

Table 1 also shows the regression methods selected in each case. Used models where regression trees (Öztürk et al. 2006; Schuh et al. 2019), support vector machines (Alenezi et al. 2008), multilayer neural networks (Wang/Jiang 2019), or linear regression methods (Sabuncuoglu/Comlekci 2002). Depending on the case study, multilayer neural networks (Asadzadeh et al. 2011; Kramer et al. 2020; Wang/Jiang 2019), the random forest model (Gyulai et al. 2018; Lingitz et al. 2018), or supported vector machines (Alenezi et al. 2008) exhibited the best prediction performance. Overall, simple regression models such as the decision tree or linear regression show poorer forecasting performance compared to more complex models (Asadzadeh et al. 2011; Gyulai et al. 2018; Kramer et al. 2020; Lingitz et al. 2018). The evaluation of the results in the analyzed studies are based on the deviations between planned and actual values. The evaluations are carried out with different evaluation ratios, whereby Root Mean Square Error (RMSE) or the normalized form NRMSE and Mean Absolute Percentage Error (MAPE) are frequently applied.

	Data		Methods									Evaluation		
	simulated dataset	real dataset	neural network	multilayer neural network	k-nearest-neighbor	supported vector machines	random forest	decision trees	boosted decision trees	linear regression	others	RMSE or NRMSE	MAPE	others
Alenezi et al. (2008)	x			x		x					x	x	x	
Asadzadeh et al. (2011)		x		x						x	x		x	
Gyulai et al. (2018)		x				x	x	x		x	x	x		
Kramer et al. (2020)		x		x			x	x	x	x		x		
Lingitz et al. (2018)		x	x		x	x	x	x	x	x	x	x	x	x
Öztürk et al. (2006)	x							x		x	x			x
Sabuncuoglu/Comlekci (2002)	x									x	x			x
Schuh et al. (2019)*		x						x						x
Wang/Jiang (2019)**		x	x	x								x		x
Welsing et al. (2021)		x				x	x	x	x		x			x

* prediction of transition time. ** prediction of order finish date

Table 1: ML methods used to determine LT in existing literature

Since the study on LT determination using different ML methods by Kramer et al. (2020) originates from the Leuphana University of Lüneburg, it serves as the basis for one phase of the learning factory training. The study examines a dataset of a real job shop production for an investigation period of about one year. On average, the initial method to determine LT (operation-specific execution time plus a generalized transition time) deviated by -12.17 days with a standard deviation of 12.95 days from the actual LT. Henceforward, a clear need for an improved determination method exists. Kramer et al. show with their comparison of the RMSE values from the different regression models that all chosen models outperformed the original procedure and that multilayer neural networks presented the best overall accuracy. They conclude, that the average deviation between actual and planned LT of the test dataset had decreased to 0.43 days with a standard deviation of 7.98 days using a multilayer neural network (Kramer et al. 2020). As the study shows sufficient results determining LT using ML, the case can function as a useful case for the learning factory training. Thus, the learning factory training uses an anonymized version of the analyzed dataset for one of the training phases. The absolved training enables participants to apply the gained competencies on a real-world dataset.

6.3. Competencies on determining lead times supported by CRISP-DM using ML

For the documentation and description of competencies relevant to the professional field, the matrix structure developed by Abel et al. for the assessment of professional-methodical competencies is used (Abel et al. 2013). It subdivides a main competence (e.g. ability to perform a method) into several sub-competencies. Each sub-competence is assigned the respective action, e.g. analysis of the actual process. Furthermore, required professional knowledge and underlying conceptual knowledge is assigned to each sub-competence.

To master real-world ML-related tasks in production environments, owning specific competencies is crucial. The necessary competencies to accomplish LT determination derive from three major fields. The fields are A) combine ML related theory with production process knowledge, B) handling CRISP-DM related processes and C) setting up a ML application. Field A reflects the main sub-competencies identified for AI literacy by Long/Magerko (2020). As the paper addresses AI applications overall, the 16 identified competencies were reduced to ten by using pairwise comparison against the relevance for a production environment.

Competence	Sub-Competence	ID
Handle ML theory in the context of production	Distinguish between general and narrow AI	1
	Recognize that computers perceive the world using sensors	2
	Recognize how computers make decisions.	3
	Understand that agents are programmable	4
	Compare different learning approaches	5
	Justify an algorithm from mathematical/statistical perspective	6
	Compare ML tools to each other empirically	7
Prepare a dataset for ML	Identify features that make an entity “intelligent”	8
	Understand that data requires process knowledge and interpretation	9
	Define scope of data mining project	10
	Setup data mining project	11
	Collect initial data	12
	Describe, examine and check the data quality	13
	Choose the relevant data for the modelling phase	14
	Format the dataset	15
Setup a ML model	Choose sufficient regression method	16
	Select applicable coding tools	17
	Avoid of the effects of overfitting	18
	Provide appropriate performance metric for algorithms	19
	Assess ML performance for the overall problem	20
	Conduct review process	21

Deploy a ML model	Determine steps needed prior to deployment	22
	Plan runtime management	23
	Implement ML into existing processes for deployment	24
Apply ML on new production related problems	Differ between challenging and suitable problems for ML	25
	Be aware of problems related to data bias	26
	Compare differences in interpretability of learned models	27
	Evaluate the effects of ML decisions	28
	Imagine possible future applications of ML	29

Table 2: Necessary competencies to develop a ML application following CRISP-DM

The 13 sub-competencies regarding CRISP-DM (field B) were extracted directly from the original method description (Chapman et al. 2000) and experiences of the authors applying the process as described in the fourth section. The original six phases of CRISP-DM have been consolidated into three major competencies being data preparation, model setup as well as model deployment. Field C consists of the twelve sub-competencies Danyluk/Buck identified to apply AI from a data science perspective (Danyluk/Buck 2019). After removing duplicate entries, the catalog is reduced from 35 to 29 sub-competencies overall. The sub-competencies originate from five identified competencies as shown in Table 2.

7. Learning factory training on lead time determination using CRISP-DM and machine learning

To enable sufficient knowledge transfer in a learning factory training, it is necessary to bring the competencies to be taught into a logical sequence so that game events are understandable to the participants. Therefore, in the present case, it is necessary to integrate the need for LT prediction into the game phases. According to the Learning Factory Curriculum Guide published by Tisch et al. (2013), the first didactic transformation defines the production type, purpose and target group of the learning factory training. To demonstrate the capabilities of ML methods applied on LT determination in a complex environment, for the new training a job shop scenario similar to the production system analyzed by Kramer et al. (2020) is applied to the learning factory. The purpose of the workshop is to enable participants to develop a ML application following CRISP-DM. Adapted from the original Leuphana Learning Factory, the target group consists mainly of professionals in PPC positions as well as undergraduate students and consultants. As the competencies to be taught have been identified in the last section, the second didactic transformation follows. It contains the definition of manufacturing processes, the manufactured product, the intended learning process as well as associated teaching methods (Tisch et al. 2013). Based on existing structures, the job shop of the learning factory handles the maintenance and repair of pre-assembled damaged model cars. The intended learning process, illustrated in Table 3, first provides learners with the necessary process knowledge for the production system. Second, learners record and prepare the dataset for ML modelling using conservative calculative methods. As a third phase, participants set up and deploy the ML model. In the final phase, learners apply a ML model on a real-world dataset.

#	Training Phase	Content	Desired result	Competen-cies
1	Socialize with the production system	Participants gain process knowledge by performing repair jobs on model cars using predefined work plans. One player schedules production, estimating LT.	LT do not meet estimations.	9
2	Record and prepare the dataset for ML modelling	Utilization of digitalization technologies to record data needed for LT determination. LT prediction using traditional tabular calculation software.	LT determination improves, but still lacks in precision.	1, 2, 3, 9, 10, 11, 12, 13
3	Set up and deploy the ML model	Participants prepare the recorded data for processing using ML. Application of regression models using RapidMiner. Evaluation on test data and another game round.	Determined LT are significantly more precise than in phase 2.	4, 5, 6, 7, 8, 9, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 28
4	Apply ML model on real-world dataset	Application of the gained competencies from phases one and two on an anonymized real-world dataset.	Participants archive results similar to those by Kramer et al.	4, 5, 6, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29

Table 3: Designed phases for the learning factory training

In the first phase, participants get in touch with the production process. In preparation on the first game round, participants receive a brief introduction to the key production logistics figures and performance indicators. Their task is to carry out defined maintenance orders on vehicles. Work plans and pre-picked part sets are provided for this purpose. Individual participants work at individual workstations, responsible for only one area, for example front wing repair. One player is given the task of transforming customer orders into production orders. The correct scheduling of different desired delivery dates is achieved by determining the planned LT based on the work plans and the current capacity utilization of the production areas. The latter must first be estimated in a self-managed manner for example by vision. The planned and actual LT of the production orders are tabulated by the instructors. In the course of production, the participants then discover that unforeseen waiting and non-productive times occur for some production orders. Reasons for delays are several predefined circumstances within the production that force delays. Circumstances are missing material at workstations or bottleneck workstations creating queues. Additionally, a high amount of work in progress and orders running through a high number of workstations lead to volatile LT that are hard to determine manually. At the end of the round, a discussion of the recorded LT takes place in the plenary. Phase 1 enables participants to gain necessary process knowledge to extract relevant data in the upcoming rounds, therefore addressing learning objectives B and C.

The second training phase starts with a theoretical input on CRISP-DM. The task of the participants is then to carry out the structured recording of the data relevant for LT calculation. For this purpose, the data needed must first be determined and then recorded. Various RFID and barcode-based time recording systems are available for this purpose. Subsequently, a second round of the game is carried out. Next, the recorded dataset is viewed by the participants and its quality is evaluated using standard office software. The second phase concludes with a theoretical input on ML methods and regression models. Additionally, the software tool RapidMiner (Mierswa/Klinkenberg 2021) is introduced. Due to its intuitive user interface and well-structured procedure for testing ML models, RapidMiner is used for the development of the ML application (Usuga Cadavid et al. 2020). Parallel to the theory input, one of the instructors statistically expands the recorded dataset. That way a dataset containing approx. 10,000 entries is generated from the initial 30 production orders carried out within the game round. Within the second game phase, participants gain competencies regarding recording relevant data and the importance of process knowledge to select suffient measurement points in the process. Phase 2 therefore addresses teaching objectives A and C.

The third phase addresses the preparation of the dataset, the modeling of the ML application and the evaluation of predicted LT using test data as well as a new game round. Again, participants first receive a theory input and then work on the task independently. First, participants evaluate the prediction quality of the estimation method used in the second round of the game and then answer some given questions about the data set using either tabular calculation or RapidMiner. The answers to the questions serve as a basis to perform the feature extraction. Subsequently, different regression methods are run in RapidMiner and the results are discussed in plenary. The third phase ends with another game round played, in which LT the best suited model is deployed into the manufacturing execution system by RapidMiner and then prediction for new arriving orders are made based on the trained ML model. A final discussion of the results takes place before the last phase starts. To master the third game phase, participants need to handle a full data mining process, containing gaining process knowledge, recording relevant data and developing a suitable ML model. To get sufficient results, teaching objectives A, B and C need to be achieved. To further check the teached competencies, game phase four confronts the participants with a new production process deriving from a real-world scenario.

In the fourth phase, the participants set up a ML supported LT determination application on a real-world case. The dataset provided to the participants is a anonymized version of the dataset of a job shop production used by Kramer et al. (2020). As Kramer et al. outline, the job shop is structured in 14 shop sections with three to six workstations assigned to each section. The dataset contains nine main production routes, containing changing work contents and job loops. The recorded maintenance orders vary in terms of external factors influencing the LT. Factors such as environmental conditions or the capacity status of the whole production system influence the LT as well as the amount of work needed to repair or maintain the given unit. This concludes in different workstation schedules for each order, which results in varying durations in process as well as transition times (Kramer et al. 2020). After applying ML by using RapidMiner (Mierswa/Klinkenberg 2021), the results, which should align with the findings from Kramer et al. (2020), are discussed. The successful development of a ML supported application on LT determination based on a real-world dataset by the participants confirms the achievement of teaching objectives A, B and C. Furthermore, the successful completion of phase four also attests the achievement of learning objective D – therefore completing the learning factory workshop.

Figure 2 on the next page shows exemplary findings that the participants could make within training phase four. The graphs demonstrate that the original procedure mostly overestimates the actual LT. In contrast, the graph created by multilayer neural networks aligns significantly more sufficient to the actual LT of those 40 orders. The results also show that a correction of the original procedure based on only the average deviation improves the prediction performance, but still lacks in precision as observed at orders number 12, 23 and 31. The workshop closes with a group discussion on further PPC tasks that could be addressed using similar ML approaches.

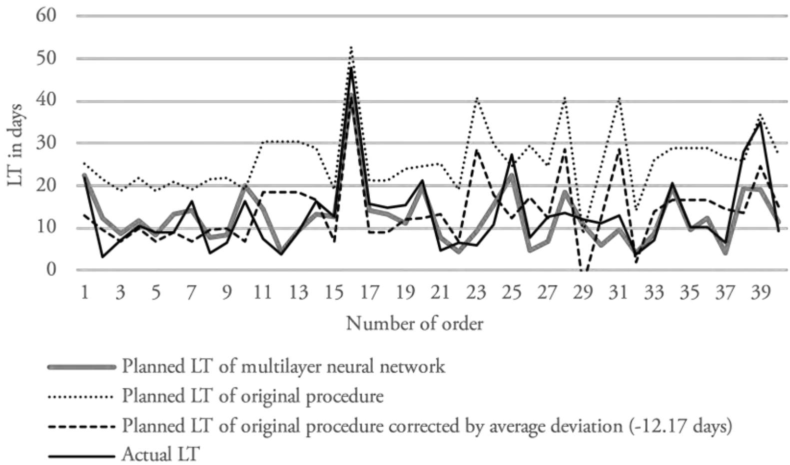

Figure 2: Excerpt of 40 orders of the test set for illustrating purposes

Figure 3 sums up how the training process enables participants to develop new ML based applications. Phase one allows the participants to gain process knowledge necessary to setup a targeted data mining process. Phases two teaches participants competencies needed to setup and execute CRISP-DM. Phase three uses the recorded dataset to teach learners the necessary competencies on developing and deploying a ML application. The fourth and final phase confronts the participants with a dataset from a real-world job shop production. Participants need to transfer the gained competencies on the given dataset to prove their ability to develop new ML applications on production related problems.

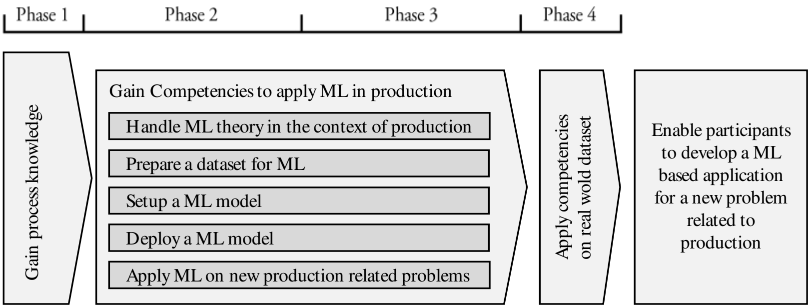

Figure 3: The learning factory training enables participants to develop new ML based applications

8. Conclusions and Outlook

Developing ML supported applications for PPC tasks requires certain competencies. Learning factories can help to acquire these competencies without influencing live production operations. For this purpose, the respective learning factories must be precisely tailored to the topics taught to enable the participants to gain the necessary competencies. Existing learning factories address ML focusing on tasks such as predictive maintenance, quality control or activity and position recognition (Daniyan et al. 2020; Hofmann et al. 2020; Oberc et al. 2020). To teach participants the necessary competencies to setup a data mining process according to CRISP-DM using ML, a multi-phase learning factory training is required. The process described in this chapter represents an approach to teach essential topics in the context of ML in production environments. Determining LT in a job shop environment serves as an example for participants to explore the topics of data mining, regression modelling and data interpretation. Follow-up tasks are to evaluate the learning success and iteratively improve the learning factory training. Additionally, the concept could be enhanced by integrating different PPC tasks or learning methods like reinforcement learning.

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Competence Development within Hybrid Value Creation

Need-based Competence Development for the Successful Implementation of Hybrid, Data-Driven Business Models

Sascha Stowasser, Nicole Ottersböck

1. Introduction

Digitalization offers a wide range of opportunities to develop companies, their services, and structures. The initial point is the handling of data and their possibility to generate information (Jeske/Ottersböck 2020). This information can be useful in very different ways for the further development of companies. Approaches to this are offered by a company's products and services, the processes required to produce or generate them, and the underlying business models (Berlage et al. 2018). A special form for digital business models is described by the term of hybrid value creation. This involves linking physical products with digital services, also known as smart services (Kempermann/Lichtblau 2012).

The hybridization of value creation and the sociotechnical work system design required for this are being explored in the research project "AnGeWaNt - Arbeit an geeichten Waagen für hybride Wiegeleistungen an Nutzfahrzeugen" (translated: Work on Calibrated Scales for Hybrid Weighing Services on Commercial Vehicles). The project is funded by the German Federal Ministry of Education and Research (BMBF) with resources from the European Social Fund (ESF) (www.angewant.de, funding code: 02L17B050). In the project, hybrid business models were developed since 2019 with a total of three pilot companies and these are now being implemented step by step. Furthermore, digital platforms for data exchange are being developed as the basis for these business models (Jeske/Ottersböck 2020).

The companies involved in the AnGeWaNt project are established in the market with their physical products. These are commercial vehicles, attachments for commercial vehicles and calibrated scales. Based on the current business models of the companies, hybrid, data-based services are being developed in the project. These can be customized by collecting product usage data. For this reason, products are equipped with sensor technology and networked with each other so that data can be collected and stored during product use and in some cases analyzed and used in real time. Based on a broad and comprehensive database, customers will be able,

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for example, to calculate more precisely the expenses incurred for completed construction work in the future. The associated experience makes it possible to carry out more accurate quotation calculations. The resulting competitive and cost-covering offers lead to advantages on the market. In addition, product usage data can be taken, for example, to enable predictive maintenance and counteract machine failure, which can help to reduce costs. Benchmarking, i.e., the comparison of product usage data from several companies, makes it possible, for example, to check whether there are any correlations between product use and machine failure. Likewise, further potential for improvement can be derived. Figure 1 shows a simplified illustration of the development of hybrid, data-driven business models, also known as smart services.

Figure 1: Exemplary, simplified presentation of the possibilities of smart services on the example of the product shovel excavator (Ottersböck et al. 2020 modified)

In addition, the concept of the project includes cross-company cooperation. The scales of one pilot company can be integrated into both the commercial vehicles and the attachments of the other companies and generate weighing data through their usage. In the future, these can provide information, for example, on which weight a wheel loader transported in which time and how much gasoline was consumed. In this way, potential for optimization in the handling of commercial vehicles can be derived and resources can be saved. In addition, improper handling of products (e.g. overloading) is counteracted and repair costs can be saved.

The further development of work design for the implementation of hybrid value creation is the central content of the above-mentioned AnGeWaNt project. To this purpose, information flows as well as work and organizational structures will first be examined and designed to suit hybrid business models. Subsequently, collaboration within companies and across their organizational boundaries as well as leadership issues will be analyzed and adapted to the needs for the successful implementation of hybrid value creation. Finally, changing competence requirements are identified and corresponding learning and teaching concepts will be developed.

These will be described below. This paper expands and deepens the presentation of the research project's methods and results from an overview paper published in 2020 (Ottersböck 2020).

2. Competence Requirements for Digitalization and Hybridization

A key success factor for the establishment of new data-driven business models and a successful digital transformation are the appropriate skills among the workforce (Seifert et al. 2018; Altun et al. 2019). Often companies be constrained in their innovative strength by a lack of competencies and skilled workers (Anger et al. 2020). The introduction of new business models therefore requires the development of competencies in the workforce. Taking targeted measures to develop competencies requires a comprehensive analysis. It is important to find out which company departments are particularly relevant in connection with the hybrid business model and what changes and competence requirements will arise in these areas because of digitalization and hybridization. For example, the companies in AnGeWaNt already identified competence requirements during the period of business model development. The identified competencies need to be covered so that the new business models can be realized. In particular, the development and information technology (IT) departments need skills in data science (programming and data analysis) and in the development of expanded, networked IT infrastructures, as well as legal knowledge, e.g., regarding to data security and data protection (Ottersböck 2020).

To implement the hybrid business model, competence development is a key activity. A four-phase approach, according to Lange & Longmuß 2015, was developed in the project to provide systematic support for competence development and a successful change process in the companies (Figure 2):

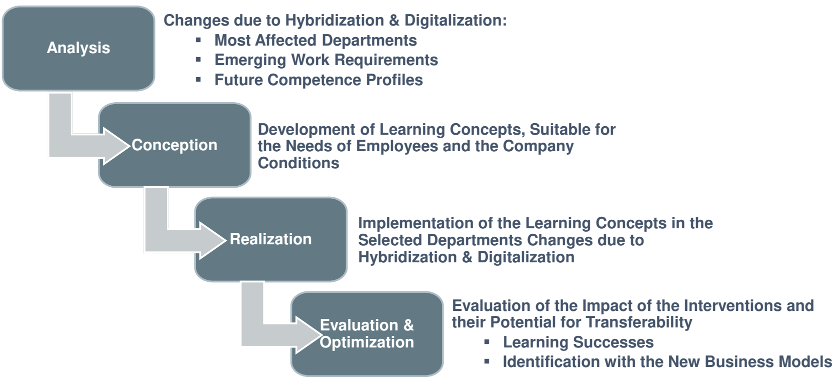

Figure 2: Four Phases of Competence Development for Hybrid Business Models in the AnGeWaNt Project (Ottersböck 2020 according to Lange & Longmuß 2015, modified)

1) Analysis phase: Identification of future competence needs that will arise as a result of the changes through hybridization.

2) Design phase: Development of learning concepts based on the results of the analysis phase.

3) Implementation phase: Application of designed learning formats in the selected pilot department.

4) Evaluation phase: Verification of the interventions and initiation of optimization as well as identification of their utility for other organizations.

Four sub steps, each building on the other, were carried out for the analysis phase:

1) Workshop, to identify changes resulting from the new business models (Chapter 2.1)

2) Cross-divisional competence check for successful digitalization and implementation of hybrid business models (Chapter 2.2)

3) Executive survey to identify changes and useful activities regarding the successful establishment of hybrid business models in the individual departments (Chapter 2.3)

4) Requirements survey to determine future competence needs and identify competence gaps in a selected department (Chapter 2.4)

The following parts describe in detail the analysis phase and exemplary results.

2.1. Workshop to Identify Changes through Hybridization and Digitalization

In order to raise awareness and to identify the changes that could result from the implementation of the hybrid business models, a interactive workshop was conducted with the project teams of the three companies. The project teams were mainly made up of employees and managers from the development and sales departments as well as human resources. In this workshop, the project teams anticipated changes that could result from the hybrid business models and systematically recorded them on a flipchart in the following four categories (see Figure 3):

- Work tasks
- Work equipment
- Work environment
- Cooperation and teamwork

Once the hybrid business models are implemented, the companies will sell smart services with product usage data beside their products. In particularly, this will require new technological competencies, e.g., for the installation of sensors, smart networking systems and the development of information technology (IT) infrastructures, as well as data science (Figure 3). It is expected that smart devices such as mobile tablets and smart glasses will be used increasingly in the future, e.g., for remote services and for the sale of products. Corresponding technical competencies must also be built up to operate these devices. Increasingly in the future data distribution will be handled via online platforms and cloud services. The project teams of the companies therefore assume that their working environment will be much more virtual in the future. This will be accompanied by increased virtual cooperation and teamwork as well as distance leadership.[1] It was also discussed that technical development is now advancing very quickly and that companies will need technically equipped creative spaces for cross-disciplinary project work in the future to be able to develop innovative ideas quickly and flexibly and try them out directly (Figure 3).

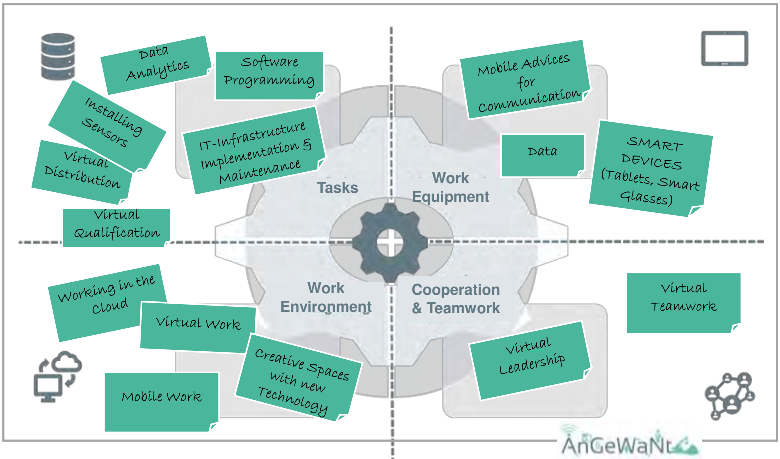

Figure 3: Examples of anticipated changes that may occur in the enterprises as a result of implementing hybrid business models (workshop part 1) (Ottersböck et al. 2020)

The quality of the results of such a kind of workshop depend significantly on how well the business models have been worked out. The more concretely the business models are, the more concretely future changes and competence requirements can

1 The workshop took place in 2019 before the Corona pandemic. The Corona pandemic and the need for virtual, mobile work have pushed the digitalization in the companies. The possible changes discussed in the workshop are therefore now already a reality.

be estimated by the workshop participants. This also applies to further activities in the analysis phase (Ottersböck 2020).

2.2. Competence Check

Based on the results of the first workshop, the second part dealt explicitly with specific competence requirements that arise in companies because of digitalization and hybrid business models. On the basis of a literary compilation of various key competencies for the future labor market, the participants were presented essential competency requirements in three categories: technological competencies, core digital competencies and, in summary, social and personal competencies (according to Kirchherr et al. 2018). Following this thematic introduction, the company project teams filled out a competency check (known as a competency analysis portfolio in Ottersböck et al. 2020), which they used to evaluate the identified future essential core competencies.

The check provides an overview of the competencies required for digitalization and hybrid business models as well as their availability in the organization, and whether these can be built up from internal specialist resources, whether external workforces need to be recruited, or whether collaboration with external providers will become necessary. In addition, an assessment was made as to whether customers will also need the expertise in the future for gaining a benefit through the data collection and smart services. Ultimately, the workshop participants assessed the priority of the identified core competencies in connection with the new business models. The highest-priority technical core competencies (priority >5) identified in the workshop are presented below (Figure 4).

The results of a study by Kirchherr et al. (2018) show that so-called tech specialists in particular, i.e., those trained in data science, programming, or web development, are needed in all industries, but represent a scarce resource on the labor market. The competence check in AnGeWaNt confirms these results, as companies increasingly need this technical know-how to execute hybrid, data-driven business models. In addition, the ability to prepare and communicate technical content in a way that is appropriate for the target audience, known in the check as "tech translation" (according to Kirchherr et al. 2018), was given high priority in the competence check, as well as hardware development, design, and administration of networked IT-systems. The last-mentioned competence is available in the pilot company, while the other competences must be built up from internal resources or even require additional external specialists for the new tasks. The companies are therefore faced with the challenge of building up competencies in the technical area, without the business models cannot be implemented. The check determined that the customers of the company also need know-how about data analytics, tech-translation and the development of IT-infrastructures so that they can benefit from data and smart services. Figure 4 shows an excerpt and exemplary result of the competence check regarding the category of technical expertise:

Competence	Available Inhouse	Can be Build Up	External Professionals/ Partners will be necessary	Competence the Customers will need	Priority 0 (low) bis 10 (high)
Data Analytics		✓	✓	✓	10
Tech-Translation		✓	✓	✓	9
Web Development			✓		8
Smart Hardware-/Robotic-Development		✓			7
Conception & Administration of Smart Network IT Systems	✓			✓	6

Figure 4: Exemplary Result of the Competency Check with a Focus on Technical Professional Competencies (Workshop Part II), Competencies according to Kirchherr et al. 2018 (Ottersböck et al. 2020 modified)

In the competency check, the companies indicated that, in addition to the core competencies, they also increasingly need expertise in dealing with digital information (digital literacy) (based on the study results of Spires and Bartlett 2012 and Kirchherr et al. 2018) as well as data protection and data security. The check on social and personal competencies revealed that employees will need to be adaptable to changes in the future and should be willing to engage in lifelong learning, which also confirms the study results of Blacke and Schleiermacher 2018 and Eilers et al. 2017. They should also have a so-called "digital mindset," be curious about new things and have an affinity for technology (Ottersböck et al. 2020).

2.3. Survey of Executives

The workshop for anticipating changes that may result from new business models showed that the new business models in the companies will have an impact on competence requirements and that new competences must be built up for realizing the business models. In the further stage of the analytical phase, the aim was now to determine the "status quo" and the impact of the business models and digitalization on the sociotechnical work system. The focus of the survey was also to determine in which specific company departments the most changes will occur and what competence requirements will arise there. A questionnaire as an analysis tool was developed in AnGeWaNt to get an deeper insight in the different company departments and their estimation of changes due to hybridization (Frost 2020, Frost/Helming 2020, Ottersböck 2020).

In two of the companies, guideline-based interviews were conducted with 14 executives from different departments based on the questionnaire. The interviews covered the following topics in particular (Frost 2020, Frost/Helming 2020, Ottersböck 2020):

- Change Management
- Experiences about the Introduction of Technology and Digitalization
- Leadership
- Corporate Culture
- Knowledge and Competence Management

The following Figure 5 illustrates the issues in the topic of knowledge and competence management:

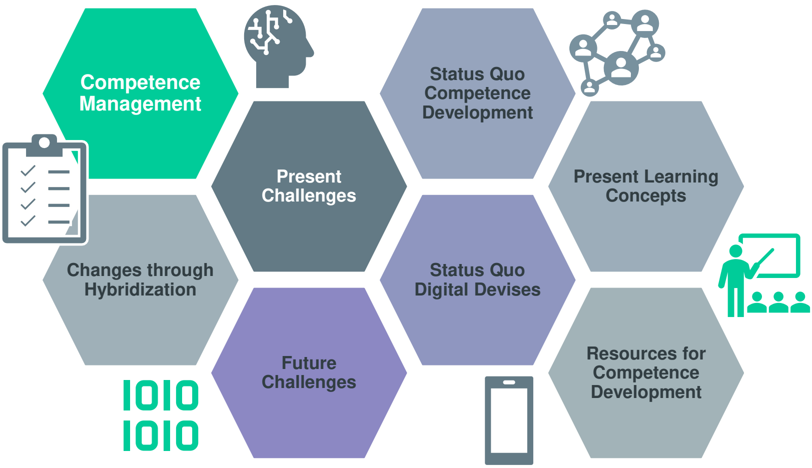

Figure 5: Range of topics in competence management in the interviews with executives (Ottersböck 2020, modified)

The interviews have shown that specially five departments in the companies will be affected by changes resulting from the implementing of the new business models. The development department is the main actor in this innovation process, as this department is responsible for and drives forward the development and implementation of the new business model. This involves a close collaboration with the IT-department, which is responsible for the IT-infrastructure and the development of the online platform which will be used to transfer the product usage data in the future. These two departments have the technical perspective in the project (see Figure 6 left side). The customer perspective is provided by the three departments application consulting, sales, and service (see Figure 6 right side). These are the areas where significant changes in the work system will result from the implementation of the new business model. The company's applications consulting division is responsible for planning and designing customers' digitalization projects. Employees in this department already have essential knowledge such as process analysis and the value of data for process optimization. The sales area (here in particular the sales customer service) has the most customer contact and will be contribute to sell the smart, data-based services in addition to the products to the customers (Ottersböck 2020).

There will also be numerous changes in the service department resulting through the implementation of the new business models. It can be assumed that the service will also have to answer questions about data provision and technical problems with the cloud and online platforms in the future. In addition, all three pilot companies are currently working on expanding their remote service and establishing digital tools for the service area.

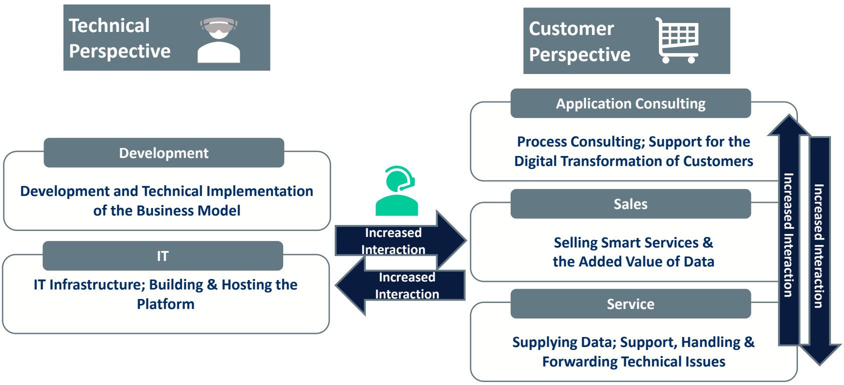

Figure 6: Identified business areas and possible changes through the implementation of hybrid business models (Ottersböck 2020)

In addition to the development- and IT-departments, the sales force in particular was identified as being important for promoting and establishing the new business models on the market. The strategy for building up competencies in the IT- and development-departments has already been defined by the company and initial measures have already been taken, such as training employees in programming or recruiting new employees or assignments of student research projects. For this reason, the sales department was selected as the model department for the more in-depth requirements analysis and competence profiling (Ottersböck 2020).

2.4. Approach for Analyzing Competence Needs in the Sales Department

The task requirements analysis in AnGeWaNt is designed to identify which competencies the workforce will need in the future to be able to implement the hybrid business models in a successful manner. For this purpose, it is necessary to anticipate future changes in their work system through the implementation of new business models. A key success criterion for a successful analysis is therefore that the employees have a comprehensive understanding of the new business model and be able to understand its value for the company and their customers. Various methods can be taken to reach employees from all departments in a way that is appropriate for the individual target group. For example, the companies in the project involved employees and executives from different departments in the development of the hybrid business models. Therefore, they organized workshops and cross-company events or asked for feedback about the results after each development step. In addition, team, and divisional meetings as well as regular contributions on the current development status in the company's own newsletter or by e-mail served to inform the workforce. To share information and for networking purposes, the company also organizes company event days where employees can inform themselves about the status of activities from other departments at theme tables. A company has developed a fictional success story or a so-called vision for publishing their hybrid business model, which is now used to inform employees from different work departments about the new, hybrid business model. This story and a published video interview with the companies' project manager about AnGeWaNt can also be used for marketing purposes once the hybrid business model is launched (Figure 7) (Ottersböck/Frost 2021):

Figure 7: Communication tools and methods used in the AnGeWaNt project to inform the workforce about the projected hybrid business models (Ottersböck/Frost 2021)

The task analysis tool TAToo from Koch & Westerhoff 2019 served as the basis for the requirements analysis in the sales department of the AnGeWaNt-companies'. The analysis manual described in TAToo was adapted and expanded to address the aspects of digitalization and hybridization in AnGeWaNt. TAToo offers guidelines for conducting requirements analyses in different ways, for example, as an interview, an observational interview during work, or in a workshop format with several participants. The choice of format depends on the operational framework conditions and the employees' daily work routine. Since the employees in the sales department work nationwide mobile and are rarely on site in the company, the analysis was realized by telephone interviews and a workshop in digital form.
In the first part of the interviews, the participants answered questions about their current tasks, activities during their workday and the needed competencies, therefore. In order to get an accurate picture of the current scope of tasks in sales, the participants were requested to describe challenging situations that they had successfully mastered in the past and which competencies they need to handle these challenges (based on Koch & Westerhoff 2019). In addition, interaction to other departments were analyzed.
In the second part of the interviews, the focus was on anticipated changes to the work in sales due to the future planned implementation of the hybrid business models. The following Figure 8 shows an example of the structure of the interviews for identifying competence requirements for successful hybridization:

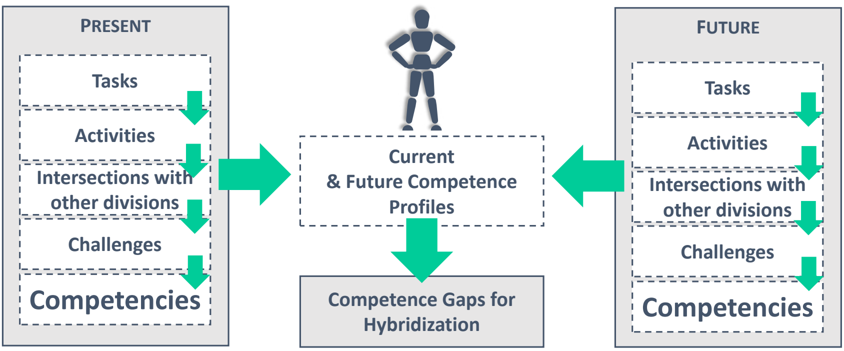

Figure 8: Exemplary representation showing the structure of the requirements analysis for the identification of competence gaps for hybridization (Ottersböck/Frost 2021 modified) (topics based on Koch & Westerhoff 2019)

The results gained from the interviews were used to identify the main working activities in the sales departments of the companies. For each work activity, the information from the interviews outlined activities, interfaces, challenges, and the necessary competencies in the present and in the future. The comparison made it possible to identify competence gaps and thereby also necessary future work skills. These results were illustrated in form of presentation slides for a following virtual half-day consolidation workshop, which took place with all employees from the sales department. This workshop was intended to complete and concretize the results and ultimately to confirm them. The consolidation workshop is only necessary if the previous analysis was conducted with interviews. The interviews can also be replaced by a one-day workshop with all employees. In this case, the consolidation workshop is not required. Both approaches were piloted in the project. The benefit of the interview variant is that all the employees' perspectives are considered, and a more detailed analysis is provided. The disadvantage is that this method is much more time-consuming, and it must be followed by a workshop to validate the results with all employees in the department. The workshop alternative, on the other hand, is not as time-consuming, but it is also not as detailed, and it is possible that not all perspectives of the employees are covered.

2.5. Exemplary Competence Requirements for Successful Hybridization in the Sales Department

The current sales of products require a comprehensive understanding of the products, technical know-how and specific electrical engineering knowledge from the employees in the sales department. In the future, employees in sales will also be required to sell smart services such as product usage data as well as process data. This requires new competencies such as the ability to analyze complex production processes for diverse customers in order to identify which data is available in the process and can provide customers with information for process optimization (Ottersböck 2020). Furthermore, it is expected that data affinity and a certain level of competencies for data analysis will be required in sales departments in the future. Hybrid smart services can only be offered if customers agree with the collection of production and product usage data. This most likely raises questions about data security precautions in the sales dialogue. Overall, it is to be expected that more technical know-how will be required in the future, for example to explain the installation and functioning of sensor technology, networking systems or cloud services (Ottersböck 2020). The following Figure 9 shows an exemplary, current and at the same time future competence profile regarding professional competencies in the sales department of one pilot company:

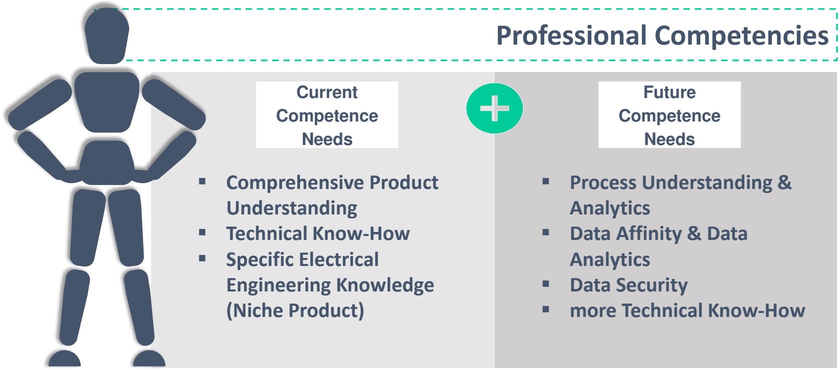

Figure 9: Exemplary, future competence profile for professional competencies in the field sales force of a pilot company (Ottersböck 2020 modified)

3. Approach for Change Management and Competence Building through Hybridization

Digitalization and hybridization are resulting numerous changes in companies. In the project, various activities, as described before, were initiated to shape the changes socio-technically in such a way that they encounter a high level of acceptance among the workforces. This also includes ensuring the development of competencies for the successful implementation of hybridization. Therefore, the employees in the sales department were involved in the development of the business models in a participatory manner. Additionally, they were asked which learning tools they would prefer to develop the identified future work skills. It has become apparent that for the employees from sales especially in the company with a more complex hybrid business model (networked data collection of products beside their original product and smart services), the value of smart services for customers did not yet seem concrete. One reason for that is that at the time of the survey, the business models were still being developed and could not yet be tested and experienced in practice. Employees therefore expressed the need to "experience" the hybrid business model and its value for customers. In addition to increased cross-divisional interaction between the technical and customer-facing divisions, "learning-by-doing", for example in combination with assistance in the form of mentoring and coaching by the application consulting and development departments, has been considered as the preferred methods for building up competence. This is in the case when there will be the requirement to analyzing customers' processes and considering their options for data-based optimization. In addition, a business simulation game is currently being developed that aims to make it possible for employees to "experience" the value of data for customer process optimization. In several rounds of the game, participants will experience the challenges in working processes and optimization potential offered by real-time data using the simulation of a gravel plant process as an example.

Business simulation games or so-called game-based learning offer a variety of essential education content for a working environment in an interactive and creative way, so that participants can derive significant benefit for their daily work tasks. The AnGeWaNt simulation is designed to help participants experience complex issues such as the optimization of a production process using data, i.e. information in real time, in an interactive setting. This learning concept has a high potential to trigger creative thought processes. The participants actively influence the course of the game with their ideas for improving the process in the respective reflection sessions. This ensures a sustainable internalization of the learning content and the possibility of transferring it to real company processes. Game based learning enhances the participants' awareness of the process as a whole and promotes the "ability to think in contexts" (Franken et al. 2019), which is identified in the study by Franken et al. (2019) as one of the essential competencies in the next five years (Conrad et al. 2021).

The following activities for supporting a successful change process and the development of competencies are considered to be effective in the project (Ottersböck/Frost 2021):

- Informing employees about the project and the progress of the development (information and awareness workshop)
- Involvement and participation of employees in the development and design of the business model
- Strengthening the interaction between the technical work departments (especially IT and development) and the customer-related areas (especially sales, service, and application consulting)
- Mentoring, cross-departmental teamwork, coaching by the application consulting and development departments

Specific learning tools are for example:

- Optimization by means of product usage and process data in real time using a simulation game respectively game based learning
- Classroom or online training on data security and data protection

4. Conclusion and Outlook

The work environment is characterized by digital technologies and rapid change. This confronts companies and their employees with numerous of challenges. To constantly adapt to new circumstances requires a high degree of flexibility, learning ability, creativity, curiosity, and willingness to change, as recent studies on competence requirements show (Kirchherr et al. 2018; Blacke and Schleiermacher 2018; Eilers et al. 2017). Digitalization and the establishment of hybrid, data-driven business models are causing changes in tasks, work equipment, the work environment, as well as collaboration and teamwork (Ottersböck et al. 2020). This requires new and modified competencies in companies. Continuous development of skills was already seen as necessary by around 78% of the 7,109 employees questioned in the "Linked Personnel Panel", a survey of companies and their employees, in 2015 (Bundesministerium für Arbeit und Soziales 2016).

The results of the requirements analysis in the sales area in AnGeWaNt have shown that hybridization is accompanied by new demands for employees. Requirements analyses for planned hybridization projects presuppose that the hybrid business idea is at a mature, concrete stage and that implementation has been planned in detail. The basis for this is also comprehensive information of the workforce about the planed hybrid business models. This is important to enable employees to imagine future work scenarios that will be associated with hybridization and the resulting changes in their work fields. A fictitious success story or vision of the execution of the hybrid business model can be support this process and also contributes to the concretization of the business idea during the elaboration. The business simulation game, which is currently being developed, is intended to make a significant contribution to ensuring that employees in sales and other departments experience the value of networked data collection for process optimization. It is assumed that this understanding can contribute significantly to a successful sale of smart services.

In addition to the analysis and measures in the sales departments, the potential of cross-company cooperation to handle digitalization and competence development in the service departments of the companies is currently being examined. In the future, there will also be an increased demand for new competencies in the service areas. An example are new remote services and the support which customers need to deal with the data platforms.

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Collaborative Approaches for Self-Organized Competence Development

Heiko Matheis, Jennifer Lucke, Meike Tilebein

1. Introduction

The ongoing digital transformation is changing work and production environments. While this leads to adaptation pressures, it also offers potential for competitive advantages. Particularly small and medium-sized enterprises (SMEs) in the European textile industry are confronted with numerous challenges associated with the digital transformation. Moreover, this sector is traditionally characterized by global competition and rapid changes in trends and markets. Under these general conditions, demand-oriented development and efficient use of competences, both individual and organizational, are becoming ever more important for success.

Accordingly, this paper covers competence development approaches on individual and organization level. The latter comprises both intra-organizational and inter-organizational activities and processes facilitating self-organized development of competences on firm level, e.g. by supporting collaboration in networks. The individual level includes activities and processes that can be directly linked to value creation on the shop floor. Hence, employees' individual competences are in focus.

On individual level on the shop floor there is a high degree of pressure on employees and their managers to adapt to changing conditions. The pressure on employees to adapt their competences is primarily driven by small production lot sizes, shorter product life cycles and faster technological advancements that quickly devalue relevant knowledge, and by fundamental change in value creation processes due to the digital transformation (Bauernhansl et al. 2018). Additional pressure results from a shortage of skilled workers and from challenges arising from the significant demographic and cognitive diversity of the workforce.

The Research Council of the Platform Industry 4.0 published a study investigating the research and development needs for the successful implementation of Industry 4.0. This acatech-study calls for new approaches to competence development and employee qualification, offering a differentiated view on leadership functions in various hierarchical, horizontal or network contexts. The study further illustrates how new decentralized and situationally adaptable solutions that enable self-orga

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nized learning paths and informal competence development are becoming a necessity for all actors in the industrial production process to acquire essential competences (Forschungsbeirat der Plattform Industrie 4.0 2019).

As much as the concept of individual competence development provides a valuable approach for the upcoming scenarios, one has to bear in mind that individual competences unfold their full potential in situations that foster their combination and interaction. Trough collaboration, complex problems can be approached and solved.

Approaches to support self-organized learning paths and dynamic, role- and actor-based models for collaborative knowledge generation already exist on organization level. There they have proven to be worthwhile, especially when considering SMEs with their specific environments and innovation processes (Matheis 2019). At the Center of Management Research of the German Institutes of Textile and Fiber Research Denkendorf (DITF), corresponding approaches for the textile industry and related sectors have been developed in recent years (Matheis et al. 2017; Matheis, Lau, Hirsch, & Tilebein 2014). From these, findings can also be transferred to production processes on shop floor level.

This paper presents challenges of collaborative competence development and approaches to solve them on different levels of the organization. Also, it explains specific implementations based on project examples.

In Section 2, the paper provides an overview of the challenges and drivers associated with competence development under the digital transformation. It describes technical advancements due to the digital transformation, as well as relevant societal trends. Afterwards, it considers resulting challenges for competence development on different organizational levels.

In Section 3, the general aspects of competence development are put into the specific context of the textile industry. After a short portray of that industry the general challenges described in Section 2 are reflected from the perspective of textile companies.

In Section 4, the paper reports first solutions towards collaborative approaches for self-organized competence development for the textile industry that match the needs and challenges described in Section 3. In detail the concepts of Smart Networks and the research projects InnoQuality, TexWIN, and TELL ME serve to demonstrate sample solutions on organization and individual level respectively. To bridge the gap between those two levels, new leadership models and the concept of self-organized learning paths present suitable approaches to implement the concept of self-organized competence development.

Finally, Section 5 summarizes the paper and points towards avenues for further research.

2. Challenges and Drivers for Competence Development Under the Digital Transformation

2.1. General Drivers

At present producing companies are faced with shorter product life cycles and faster technological advancement that lead to a constant need for innovation. The focus thereby moves towards increased individuality in products and services. The employees in development and value creation processes not only have to handle the increasing variety of customer-specific products, but also innovations in production processes and technologies. This way, routines have to be adapted permanently and novel competences to deal with new technical systems have to be developed (Forschungsbeirat der Plattform Industrie 4.0 2019).

German producing companies, and SMEs in particular, have a long-standing tradition in highly specialized value creation. Their development and production activities are based on knowledge-intensive processes and knowledge work featuring high complexity and continuous innovation. In this area specific work-related experiences and creative problem-solving skills of employees are highly in demand. At the same time, an academization trend is taking place. More young people than ever are pursuing a university degree, thereby replacing other forms of education such as apprenticeships or dual training programs which further increases the need for automation in production. (Hertle et al. 2015) Furthermore, demographic change accounts for greater diversity as well as greater differences in society and workforces (Hilf & Tilebein 2013).

Given these conditions, ongoing adaptation and learning becomes essential. Turning to customer-specific products which are characterized by unique orders and individual requirements, learning becomes particularly necessary. While fixed routines are still applicable on the overall process level, specific problems arising from each individual order differ from each other. (Hube 2005)

While the digital transformation accelerates the ongoing changes by increasing the pressure on organizations to adapt, it also provides opportunities to manage these changes. Assistance systems can for example provide help by supporting staff in value creation processes. (Bauernhansl et al. 2014)

On the technical side, decentralization and self-organization in the areas of interaction, information processing and decision-making are relevant principles of Industry 4.0 applications. These principles bear great advantages for system adaptability, robustness and resilience.

However, so far the application of these principles has mainly focused on the technical subsystems of the Industry's socio-technical systems. In order to make their socio-technical systems thrive as wholes, companies have to embrace the new chances arising from the digital transformation and to permanently develop their competences according to need throughout all organizational levels. (Adam et al. 2019; Vernim et al. 2019)

2.2. Competence Development on Organization Level

On organization level, it is the organization's task to identify, develop and use competences in order to enable innovation and organizational learning. Organizational competences are complex high-level organizational routines that meet specific market requirements. In this sense, they are valuable resources that can contribute to maintain a sustainable competitive advantage. Thus, from an organization's view, a main challenge resulting from the changes mentioned above is to integrate and embrace staff and competence diversity on all organizational levels. Diversity should be turned into a resource for competence development and renewal and for gaining competitive advantage in the ever-changing environment of the digital transformation, while balancing exploitation and exploration. (Tilebein 2007)

In addition, the constant need for innovation in combination with an increasing digitization of products and processes requires companies to acquire new competences outside of their core competences. Competence development through learning from other experts and the ability to collaborate within networks are therefore becoming key to successful innovation (Mazzerol & Reboud 2008; Nonaka et al. 1997).

However, in order to integrate external knowledge companies face the challenge of opening their own processes to customers, suppliers, complementors and competitors (Dooley & O'Sullivan 2007; Müller-Seitz 2012). Considering competences and information as a resource, mere access to competences and information is usually not sufficient to achieve competitive advantage. This means that the competence to cooperate with partners in networks is becoming more and more important and, through the resulting exchange of knowledge, is increasingly becoming the key to successful collaboration (Lau & Tilebein 2013).

Temporary innovation networks are formed featuring a collaborative and project-like environment. These networks are further characterized by a variety of autonomously acting participants with different goals, cultures and work contexts (Camarinha-Matos & Afsarmanesh 2005). In order for such a dynamic network to be temporarily successful, new competences in leadership and self-organization of all participating actors to coordinate and control the activities within the collaboration are essential.

Various concepts address these missing collaboration competences on organization level. Agile management, actor-oriented architecture, Smart Organization and Smart Networks derived from the latter are concepts already introduced utilizing an agile, actor-oriented, and role based approach to collaborative work (Filos 2006; Fjeldstad et al. 2012; Lau et al. 2015). However, the successful implementation of these dynamic network concepts depends on the ability of companies to develop new competences in these novel collaborative forms of value creation. This comprises learning new tools, processes and methods.

Looking at the concept of Smart Networks in particular, initial approaches on how innovation processes in smart networks can be supported from idea to market launch are described (Matheis, Tilebein, Hirsch, & Lau 2014). In these dynamic networks actors can take different roles over time, which results in the need for dynamic positioning of all participants. This presents the challenge of developing actor specific as well as situation and process specific competences.

2.3. Competence Development on Individual Level

The general drivers described in Section 2.1 also affect individual competence development of production personnel on the shop floor (Tenberg & Pittich 2017). The activities in production are changing in terms of complexity and frequency of renewal. Renewal in this sense describes activities with which employees are confronted for the first time and for which they cannot fall back on approved solutions from own experience-based knowledge (Hube 2005). Complexity and novelty are the two defining dimensions of the concept of so-called "knowledge work". This form of work is required when activity-related problems cannot be solved routinely and are highly complex.

A first challenge when it comes to individual competence development is to provide a reliable measurement system of competences in socio-technical production systems. This is necessary to find a balance between available and needed competences (Jacobs et al. 2021). Such a measurement could build the basis for a competence development process including the phases of learning initiation, interaction, cognitive problem solving, operational solution implementation and reflection on the performance of the activity (Sobbe et al. 2016). In addition to implementing a dedicated competence development process, designing a structured approach to identify the required competences of employees with respect to future work conditions (for example the usage of assistance systems, digital assistants, or exoskeletons) presents a challenging task. (Vernim et al. 2019)

A second challenge regarding individual competence development is to enable situation specific work-based learning (Jacobs et al. 2021). Consequently, "knowledge work" must be implemented in the form of informal but intentional work-based learning in order to promote competence development. In this context, technological and methodological support could enhance competence development.

Thus, providing technological support for work-based learning is a driver, but also a challenge for individual competence development. In any innovation context there are barriers to overcome. In the context of individual competence development this means to create technological solutions which are accepted by the employees and furthermore foster the motivation for situation specific work-based learning. Therefore, ergonomically accentuated digital assistance systems can be used to provide information that specifically support employees in problem solving, decision making and reflecting on solutions (Adam et al. 2019).

3. Specific Situation in the German Textile Industry

3.1. General Overview of the Textile Industry

The German textile industry, one of the most important consumer goods sectors (BMWI 2021; Umweltbundesamt 2019), is characterized by a large number of differently positioned SMEs and by operating under cost pressure. With its more than 1,400 companies, it generates an annual turnover of around 32 billion euros (of which around 60% account for textiles and 40% account for apparel), making it the market leader in Europe. In particular, small and medium-sized enterprises (SMEs) characterize the textile and clothing industry; 93% of all companies have less than 250 employees. Besides the clothing sector, the German textile industry is supplier for several other industries such as the rubber and plastic industry, the automotive industry, mechanical engineering, the electrical industry, and the construction industry. (Textil+mode 2021a, 2021b)

Being a supplier industry, the German textile industry has to cope with a wide range of requirements from various customer industries. In this situation the textile industry benefits from the flexibility of the existing textile machinery, that is basically able to handle different materials such as traditional textile semi-products as well as new textile products like carbon fibers or metal wires. Thus, textile manufacturing processes offer a multitude of possibilities, if the industry succeeds to close the gap between technical possibilities, integration requirements and necessary competences. (Artschwager et al. 2017)T

he capability of the textile industry to combine traditional and "new" materials is related to traditional frequent changes in customer behavior and market structure. The German and European textile industry undertook a major change in the fields of application. It turned from mass production to knowledge intensive products for new markets and high technology applications such as smart textiles, medical devices or lightweight structures. Therefore, the development of new business models such as collaborating with other sectors is a key success factor for modern companies in the textile industry. (Tilebein 2017)

The general development in the manufacturing industry towards lean processes and structures has resulted in highly specialized companies also in the textile industry. The expertise within the companies, which are often times SMEs, is limited to specific process stages. However, increasing customer requirements and increasing complexity often require knowledge exchange across several process stages. (Artschwager et al. 2017)

Similar to other industries, the textile and clothing industry is in the midst of a digital transformation, which requires a fundamental structural change of organizations, processes, and information and communication technology (ICT) infrastructures. While the current ICT infrastructure of companies often is designed for specialized and self-contained activities within the organization, the digital transformation now also enables digital exchange with partners and customers in dynamic networks. Nevertheless, the current systems are neither designed for this nor do the employees have the corresponding competences. Furthermore, the demographic situation within the textile and clothing industry together with the decline in qualified workers requires new solutions for work-based competence development. (Artschwager & Tilebein 2017) Thus, in the textile industry, just like in the producing industry in general as sketched in Section 2, there is a strong need for approaches towards competence development on organization as well as on individual level, and in the alignment of the two.

3.2. Challenges on Organization Level: Product and Process Innovation

High value-adding processes for knowledge-intensive textile products and services are facing growing complexity and therefore call for close partnerships. Especially for companies which are increasingly acting across sectoral borders functional as well as technical interoperability has become tremendously important. Only by trustful collaboration between partners, required knowledge and competence can be acquired, shared and used to develop targeted innovative products and services for new customers and target markets. However, even after including the right partners in the first phases of development, companies have to ensure that competences gained in these early steps will be available throughout the whole product life cycle in order to guarantee the efficient and sustainable production of products and/or the delivery of valuable services. (Dooley et al. 2016)

Furthermore, continuous work-based competence development is of great value also for the next generation of products and services, due to the extremely growing complexity of scientific, technical, and business requirements for high value products and services. Competence development has thus to be recognized and treated as valuable resource within textile companies and across their network of partners and should be supported by appropriate ICT structures. (Filos 2006)

Consequently, significant challenges in particular for SMEs emerge. The first challenge is to establish a network for the development and production of knowledge-intensive products and services. Therefore, the identification of the knowledge and competences needed throughout the product life cycle is crucial. The requirements towards partners can change due to the evolution of various needs and opportunities. The network requires flexibility to handle such dynamics. Changes in partnerships or roles of partners should have no or very limited influence on the management of those collaborations. Therefore, the competence of leading employees should enable a robust and flexible organization. (Filos 2006; Matheis et al. 2017)

The involvement of customers in the development processes increases the complexity of product and service designs. Without proper monitoring of the development status and resources in a network, the efficiency of the development processes can decrease and costs can increase dramatically (e. g. many development iterations due to permanently changing requirements). Networking and the idea of open innovation require a strong support of SMEs and in particular of their employees in all tasks arising in the product life cycle. (Du Chatenier et al. 2010)

Another challenge for SMEs is to cope with the management and transformation of knowledge along the product life cycle. During the process knowledge and competences from various partners are used to form new knowledge. Competence development has to deal explicitly with the availability of the required competence at the right time but also with the conservation of new competences for later phases of development and production.

3.3. Individual Level: New Challenges on the Shop Floor

The ongoing transformation of the textile industry accounts also for fundamental intra-organizational changes in engineering and production.

As an example, the Digital Textile Micro Factory features end-to-end integrated digital design and production processes and can therefore be regarded to as a milestone for the textile industry on its way to Industry 4.0 (Tilebein 2019). However, the Micro Factory comes with a new set of challenges to be addressed. This new process provides a range of possibilities including completely new business models in the areas of individualization, sample production, reordering and event-driven production (Deutsche Institute für Textil- und Faserforschung 2019).

At the beginning of this process scanning devices and smart services allow for individualized product configurations (Artschwager & Tilebein 2017). Putting the customer in a central position and fostering direct communication directs the whole design process towards the customer and extends the value chain into the market. Customers are becoming prosumers, who are empowered to design their own products by themselves (Moltenbrey & Tilebein 2020). These individualized garments do not only cover different body shapes and sizes, but also play an important role when it comes to physical disabilities. Here, Digital Textile Micro Factories create the necessary diversity to outfit all individuals (Artschwager & Tilebein 2017). At the same time, the production systems themselves are becoming smart. Being equipped with a range of sensors, the production machines can independently monitor their current status within the production process and manage their maintenance schedule with the help of predictive maintenance algorithms (Artschwager & Tilebein 2017).

In spite of integrated digital technologies people remain at the center of all these developments. The digital transformation in socio-technical systems stresses the importance of skilled employees and their individual knowledge. In line with that, the need for ongoing competence development through work-based learning is increasing steadily. (Artschwager & Tilebein 2017)

3.4. Bridging the Gap from Individual to Organization Level

The needs sketched above in terms of organizational competences, which are required for using the innovation capability of dynamic networks, and individual competences, that have to be acquired especially with regard to new digital technologies and individualized products, have to be addressed by competence development activities on either level, be it individual or organization level.

In addition, since a large part of organizational competences in the textile industry is based on personal competences of experienced staff, the individual and the organization level have to be aligned properly. This bears a specific challenge for firms not only in terms of their competence development strategies, but also in terms of their strategies for competence utilization.

At the same time, the textile industry in Germany is experiencing a particular shortage of skilled workers. Many experienced employees will retire in the next few years due to the industry's age structure, while a lack of industry attractiveness leads to recruiting problems in Germany. The reason for this missing attractiveness is that the textile sector in Germany, despite its transformation into an innovative hi-tech industry, still struggles with a poor reputation and an outdated image from the perspective of potential employees. This is why textile companies face a broad range of diversity in their workforce, in terms of e.g. age, skills, cultural background, industry or workplace experience, affinity towards ICT etc.

Against this background, companies in the textile industry need to rethink their strategies for competence identification, competence development and competence utilization and look for appropriate methods and tools supporting these strategies.

4. Solutions and Open Research Questions for Collaborative Approaches for Self-Organized Competence Development for the Textile Industry

4.1. Solutions on Organization Level

The concept of collaboration in networks is already being used extensively in terms of cooperation between companies. Hereby, they work together in temporary and variable compositions. Especially for small companies with very specific competences this approach is a model for success. The concept of Smart Networks which was developed in the EU funded project SmartNets[1], describes an industrial model to support SME collaboration in the day-to-day business of SMEs. This model is applicable along the complete product life-cycle of different industry sectors. The implementation of this industrial model into practice is based on several methods and tools. Therefore, the methods have a clear focus on SME suitability considering a clearly described and easy to follow process complemented by examples. Furthermore, most of the developed methods are accompanied by tools which act as assistance systems that allow a self-organized learning of the methods during application. (Lau et al. 2015)

The successful implementation of the role- and actor-based model within Smart Networks depends on the ability of SMEs to know their exact position within the process as well as possible next steps at any time throughout the collaboration project. The Smart Net Collaboration Model builds the frame for the Smart Networks industrial model by orchestrating activities within the process, actors within the network and methods to be applied. Thus, the Smart Net Collaboration Model provides answers to key questions like "What to do next?", "Who can do it?", "Which method could help me?". (Lau et al. 2015)

One of the tools to support the implementation of the collaboration model is the Smart Net Navigator which supports the self-organization of specialists and managers across company boundaries as well as self-organized learning and application of the underlying innovation process. This digital assistance system helps actors to navigate through the ongoing innovation process by monitoring their current position within the innovation process and finding the answers to the above mentioned key questions on "actors to involve", "methods to apply" and "steps to perform". Thus, the Smart Net Navigator fulfills both the function of a project cockpit, which determines and displays the current project status, and the function of an advisor and trainer, who points out possible next steps in the process and suggests the methods required for this and other actors to be involved. (Matheis et al. 2014)

In addition to engaging in the self-organized application of a given innovation process as well as navigating through one, configurating a generic innovation process in an assisted but self-organized and needs-based approach presents the next step. To address this need was the goal of the project InnoQuality[2]. As a result of

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1 The European research project „ SmartNets – The Transformation from Collaborative Knowledge Exploration Networks into Cross Sectoral and Service Oriented Integrated Value Systems" (CP-FP 262806; SmartNets) aims to establish and to prove 'Smart Networks' as a holistic industrial model for sustainable and efficient production in cross-sectoral SME collaboration both in development and production of knowledge-intensive products and services.

2 The collective research project " Improving the Quality of Innovation Projects in the Field of Interior Textiles " (IGF 116 EN; InnoQuality) aims at optimizing the innovation funnel at interior textile companies.

this project, for the textile industry and in particular for the home textiles sector an interactive guideline was presented that supports and accompanies companies in the home textile industry in the description, evaluation and processing of development projects. With the guide, managers from the development area can design the development process themselves depending on the particular technical and organizational challenges of their respective framework conditions in order to ensure innovation quality even with complex requirements. The interactive guide follows a case-study based approach to identify success factors for innovation and the associated process configuration. In this context, the transfer of knowledge from past successful, but also from unsuccessful innovation projects plays a decisive role in the success of future innovation projects. Beside the implicitly transferred knowledge through suggestions of the guide, this concept uses the method of storytelling to explicitly explain why considering specific success factors is crucial for specific project designs. (Matheis et al. 2017)

In line with the benefits of this approach on organization level, the principles of collaboration in networks and of self-organized problem-specific process configuration can also be transferred to lower organizational levels. Implementations can take place on all levels including the shop-floor level to establish a work-based competence development through self-organized learning paths.

4.2. Solutions for Digital Assistance Systems for Work-Based Competence Development on Shop Floor Level

The German industry and in particular the textile industry currently experience a development in value creation towards increasing knowledge work while at the same time routine activities are becoming less frequent. This ultimately leads to a scenario in which every order is unique and requires a specific process solution as laid out in the context of the Micro Factory in Section 3.3. Employees performing the processes therefore need to be equipped with opportunities to work out individual solutions immediately. The concept of lifelong learning is still applicable in this context. However, instead of taking place off-site during educational trainings, this new form of learning happens directly during the value creation process. This way value creation and learning merge into work-based learning making continuous competence development the preferred approach. Being referred to as "learning on demand" this new approach requires not only self-determination, but also self-direction from the learners. The opposing idea of "learning ahead" on the other hand is losing importance. Since the content and time frames of competences to be acquired differs from individual to individual, self-organized learning paths provide an optimal solution to that. (Hertle et al. 2015) Within the textile industry there are some new concepts for work-based learning in pilot scale already elaborated and evaluated. The first concept which was developed within the European research project TexWIN[3] applies a case-based reasoning method mainly to combine human experience with information from other sources to improve the stability of production processes even for individually designed products. The underlying digital assistance system supports the employees in their work through pre-selected information while the decision-making authority remains with them. Case-based reasoning as an assistance system can be integrated easily into the production processes of textile companies, because the process of case-based reasoning has long been part of the daily work of many employees also in a non-digital form. It is the process of using former experiences and adapting them to new, similar situations. In the textile industry it is applied, for example, to determine initial machine settings for new or modified products or the adjustment of machine settings during operation in the event of poor performance or frequent process downtimes. Even if workflows using ICT-supported case-based reasoning are hardly different from conventional workflows, their implementation in the day-by-day business in not trivial. The employees have to be convinced to share their individual knowledge with their colleagues to individually benefit from the knowledge within the company. Thus, a living case-based reasoning system supports the workers on the shop floor in their individual competence development through the collaboratively filled case base. (Weiß et al. 2017)

Within the framework of TELL ME[4] a second solution for work-based learning was developed, which focuses on the assessment of different technologies and learning methodologies. The framework aims at variable processes with knowledge work in various industries and tested ICT applications and assistance systems at the production level in helicopter and yacht construction as well as in the textile industry. In helicopter construction in particular, the consortium developed and tested a specially developed ICT-supported process model for knowledge work in the area of maintenance and services, which focused on demand-oriented learning when leaving routine processes. In the textile industry, software supported precision teaching for fabric inspection and the detection and correction of faults in particular - especially new types of faults from different fields of application were addressed. Using the method of precision teaching employees learn appropriate correction measures when certain faults occur as well as basic correlations and technical vocabulary. Compared to conventional training methods, this approach

3 In the European research project "Textile Work Intelligence by closed-loop control of product and process quality in the Textile Industry" (CP-FP 246193-2 TexWIN), textile research institutes as well as textile companies and textile machinery manufacturers were involved as users of the solutions developed. of the textile machinery industry were involved as users of the developed solutions.

4 The European research project „Technology-Enhanced Learning Livinglab for Manufacturing Environments" (CP 318329 TELL ME) aims to develop and trial an innovative cross-enterprise methodology and IT platforms for continuous education and training in small and medium manufacturing environments for work-based competence development.

leads to a significantly shorter training time and better comparability of learning results. A second technology-based approach tested with in the textile industry was an augmented reality application for the set-up of weaving machines. Since setting up weaving machines is knowledge-intensive and time-consuming, the use of augmented reality (AR) facilitates the set-up-process and the retrieval of specific information. The process steps and explanations are simply superimposed on the AR glasses and the worker is guided through the entire process in this way. (Winkler et al. 2015)

Since assistance systems and human-machine collaboration have to be adapted to specific workplace requirements, individual and customizable designs are essential. Additionally, systems need to be able to evolve in line with changing conditions and different user demands. Central questions in this regard that remain to be answered include how to deal with topics of liability and servantship in socio-technical systems.

4.3. Open Questions Regarding the Alignment of Individual and Organizational Competence Development

As sketched above, companies in the textile industry need to rethink their overall strategies for competence identification, competence development and competence utilization. Specific solutions and tools already exist both on organization and on individual level. However, these are not aligned. Strategies are needed that balance top-down central approaches with self-organized bottom-up decentral approaches and fit to and align different organizational levels. Additionally, these strategies should integrate and support aspects of human interaction and collaboration, as it is the case in interorganizational innovation processes, as well as human-machine collaboration, and largely digitalized knowledge-intensive processes just like in the Micro Factory.

The respective strategies should build upon and make use of staff and competence diversity as a resource. The focus ultimately lies on the cognitive diversity of employees which arises from their different skills and talents. This diversity and its interconnectedness make innovative and creative solutions possible in the first place.

These strategies also require a new understanding of leadership. Similar to the shift from centralized information processing and control towards decentralized decision-making in technical systems that is one of the basic ideas of Industry 4.0, there is a need for corresponding models for the human-related parts of the socio-technical systems that are involved in any of the industry's processes.

Complex adaptive systems are agent-based systems that exhibit emergence. This term describes the generation of macro-level properties arising from self-organized micro-level interactions without them being planned or foreseen. Complexity science's theoretical perspective is far from generating a comprehensive and ready-to-use solution for the challenges described above. However, it can provide a useful integrative framework and complex adaptive system models offer a valuable theoretical approach towards new insights into self-organized competence development. Complexity leadership theory (CLT) describes the corresponding leadership theory which allows to use the principle of emergent qualities from self-organized interactions throughout all organizational levels and with their respective organizational actors (Uhl-Bien et al. 2007).

In the CLT framework, which is explicitly depicted as a new leadership paradigm for knowledge-generating organizations, a distinction is made between three basic leadership functions that are called administrative leadership, adaptive leadership, and enabling leadership. Administrative leadership includes classic management tasks such as planning, coordination, goal setting, resource allocation, conflict resolution and the like. Adaptive leadership ensures the adaptability of the system under consideration. This function focuses on the emergent quality of leadership and its emergence from interaction processes of actors. The drivers of these processes are the actors' heterogeneity and asymmetries, which are present not only in the classic sense in terms of power, but also in terms of knowledge, skills, and so on. In relation to adaptive leadership, enabling leadership finally has a catalytic function and thus has the task of creating framework conditions in which adaptive leadership can show itself and develop. The possibilities from the spectrum of administrative leadership can also be used for this purpose.

In the area of administrative leadership, certain aspects like fostering an integration in the organizational hierarchy and goal system, support the necessary alignment of individual learning on the shop floor level with external goals addressed. Turning to the adaptive leadership functions, on the other hand, links to self-organized, informal and collaborative learning processes and learning paths that are embedded in networks can be observed. Finally, enabling leadership contains the tasks of shaping, moderating and handling the area of tension emerging from the previous two leadership functions, depending on the situation.

The CLT framework can support the idea of using diversity as a resource and enabling self-organized collaborative learning and the emergence of new competences while aligning the respective processes throughout organizational levels.

5. Summary and Outlook

The ongoing digital transformation radically transforms work and production environments. For the manufacturing industry this means major adaptations become necessary to secure their competitiveness. For the textile industry, which mainly consist of SMEs and the German textile industry in particular, this implies the need to face the emerging challenges on top of the traditional challenges coming from global competition and rapid changes in trends and markets.

Facing these challenges, the textile industry in Germany in particular will, due to an increasing number of retirements in the next years, face a broad range of diversity in their workforce. Consequently, solutions to promote the development of individual competences are necessary. In addition, personalization and increasing complexity of products or shortened technology and product life cycles influence traditional production activities on the shop floor. This ultimately leads to a scenario in which every order is unique and requires a specific process solution. Thus, a breaking of routines that typically lead to the learning of new workflows is the consequence. In particular lean and highly specialized SMEs in addition to their competence in developing specialized products increasingly need competences that go beyond their organizational borders. Therefore, focusing on core competences without supplementing them with organizational and individual competences for collaboration is no longer sufficient.

Hence, collaborative approaches for self-organized competence development according to individual needs on any organizational level are required. The industry needs concepts, methods and tools (e.g. digital assistance systems) to establish self-organized learning paths on every organizational level, from the organization level to the individual level on the shop floor, and to manage their alignment.

This paper presents some already existing solutions for work-based competence development on the shop floor as well as solutions for the development of organizational competences such as the capability to collaborate in networks. Nevertheless, there are still open questions to elaborate on. Future research topics include personalization and optimization of assistance systems, collaboration scenarios that consider all parts of socio-technical systems, as well as methods and tools for self-organized collaborative competence development throughout all organizational levels. They have to be complemented with leadership models that are able to bridge the gap and support the alignment of the different organizational levels.

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Towards a maturity model of human-centered AI – A reference for AI implementation at the workplace

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1. Introduction

Currently there is a third wave in research on artificial intelligence (AI) (Launchbury 2017). In parallel there is a high interest in AI-implementation in organizations (Schuler et al. 2019) and an increasing number of examples where AI is implemented in the workplace (McKinsey 2020; Baruffaldi et al. 2020). Going into more detail it becomes obvious that AI in practice can rather be traced-back to research outcomes from the second wave that emphasized the complementary expertise of AI in correspondence to human intelligence (Brynjolfsson/McAfee 2017; Wilkens 2020) while the third wave in AI research is aiming at an almost perfect copy of human intelligence (Deng 2018). This is an important distinction for workplace analysis and research dedicated to AI implementation.

This paper addresses the implementation of AI at the workplace while suggesting a maturity model of human-centered AI that elaborates on already existing maturity models. The outline refers to typical use cases for current implementation of AI and thus goes beyond the industrial sector. The core emphasis lies on AI-based functions such as enhancing precision, supporting quality control or decision making, protecting security etc. which matter for a variety of work settings in high-tech environments across certain industries. This variety of use cases also increases the number of disciplines involved in the implementation process of AI and leads to different and co-existing interpretations of what human-centricity exactly means and implies for job design. This is why the blueprint includes and combines certain dimensions and criteria indicating how to operationalize the human-centricity of AI and explores a fan structure of the blueprint that allows to set the focus related to context-specific demands during the implementation journey.

In the following paragraphs we will first give attention to typical outlines of maturity models in the field of digitalization. Moreover, we elaborate on a distinct understanding of the human-centricity of AI in order to specify criteria supposed to operationalize the maturity of a human-centered integration of AI in the workplace. The most challenging part is to not just list criteria which are considered as

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relevant in principle but to give evidence to the interrelatedness of these criterin correspondence to the context of implementation. In order to cope with this challenge we refer to qualitative case descriptions from different work settings.

The fan structure of our approach allows to refer to the sociomateriality of technology (Orlikowski 2007; Orlikowski/Scott 2008) and to avoid a techno-centric perspective.

2. Components of a maturity model of human-centered AI

2.1 The way maturity models work

Maturity models in general are assumed to be a helpful tool for describing the state, potentials, and demands within a functional domain (Wendler 2012). Organizations might draw on maturity models to evaluate their status quo and to encourage and monitor a step-wise further development within an implementation process (Alsheibani et al. 2018; Leineweber et al. 2018). In this regard maturity models can also help to leverage capabilities in a specific domain (De Bruin et al. 2005) and to enhance their strategic potential (Alsheibani et al. 2018). With respect to AI-based human-computer-interaction in job design we can elaborate on and further combine two different types of maturity models. The first type is especially helpful to give attention to a comprehensive view in the implementation process. This can be exemplified with the maturity model from Klötzer/Pflaum (2017; see Figure 1).

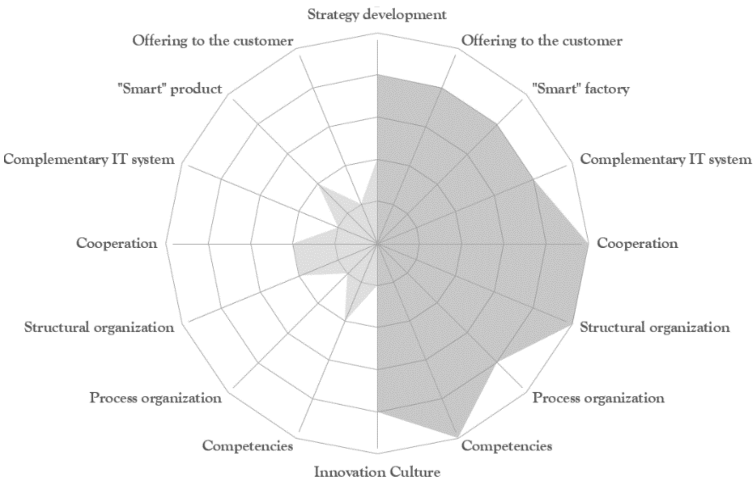

Figure 1: Maturity in the implementation process; own illustration based on Klötzer/Pflaum 2017

The model is not specified for AI but for the digitalization journey of an organization.

The advantage is its comprehensive view of technological, organizational and workforce related components. The shortcoming is that interdependencies between these dimensions are not taken into consideration and that the interrelatedness between technological and human action is not in the center of the approach.

The second type we can elaborate on is represented by the "AI management framework" from Lichtenthaler (2020) as it reflects on the integration of human and artificial intelligence. Low maturity is characterized by experimentations with selected AI technologies in organizations ("initial intent"). High maturity is testified when there is a shared management of human and artificial intelligence ("Intuitive Ingenuity") that involves leveraging pooled, sequential and reciprocal interdependencies between human and AI ("integrated intelligence"). The core argument for the implementation process is that the interrelatedness of AI with the social system is an expression of higher maturity for gaining competitive advantages. The maturity model helps to identify and exploit so far unrealized opportunities while making use of an integrated intelligence structure in organizations (Lichtenthaler 2020). A shortcoming of this model is the missing integration of contextual factors and the underlying assumption that there is one best way to interrelate artificial and human intelligence even though there are co-existing ideas of what human-centricity of AI means (Wilkens et al. 2021). Moreover, the maturity of the technology itself tends to be taken for granted even though there are considerable challenges the implementation process has to cope with.

Level	Name	Description	Impact
+	Intuitive Ingenuity	Shared management of human intelligence and AI; self-awareness systems with some consciousness, emotional intelligence, and ingenuity (only in the future)	Very High
5	Integrated Intelligence	Renewal and recombination of human intelligence and AI; leveraging pooled, sequential, and reciprocal interdependencies for completely novel solutions	
4	Interdependent Innovation	Emphasis on AI for innovation beyond efficiency; sometimes pooled and sequential interdependencies of human intelligence and AI; often corporate orchestration for synergies	
3	Interactive Implementation	Exploitation of multiple AI solutions; sometimes pooled interdependencies of human intelligence and AI; often coordination of activities in multiple organizational units	
2	Independent Initiative	Ongoing AI initiatives; typical emphasis on advanced automation and enhancing efficiency of established processes; often started in selected organizational units	
1	Initial Intent	Initial steps of experimenting with selected AI technologies; exploration of feasibility and viability; limited implementation in uncertain context	

Figure 2: Maturity as integration of human and artificial intelligence; own illustration based on Lichtenthaler 2020

While both introduced models give inspiration maturity models emphasizing the pure technological readiness of AI applications in the workplace (e.g. Aronsson et al. 2020) represent a less helpful direction for the aim of this paper as they have low potential to face human-centricity of technology in an adequate manner.

To sum up, so far there is no maturity model reflecting a deeper understanding of what human-centricity of AI means and that at the same time allows to reflect on the technological advancement and to come in close with a comprehensive view of technology implementation.

2.2 The (multiple) perspectives of human-centricity of AI

There is a wide range of interpretations across disciplines of what human-centered AI exactly means. In their literature review Wilkens et al. (2021) identify five different perspectives – a deficit-oriented, a data reliability-oriented, a protection-oriented, a potential-oriented and a political-oriented understanding of human-centered AI (see Figure 3).

The **deficit-oriented understanding** of human-centered AI considers AI as beneficial and helpful to compensate individual weaknesses and failure in attention, concentration, physical and mental fatigue. According to this understanding the maturity of human-centricity can be measured with respect to the *failure control function of the technology*. A high maturity level in this regard indicates that technology prevents the human being from time consuming monotonous work and individual fatigue due to these exhausting job characteristics. This concern is often stressed in health care and clinical settings, for example to relieve nurses of constant tracking activities of health parameters (Adnan et al. 2020). An example from production settings is the use of AI for analyzing photographs for quality control reasons of welding seams. Another example in the field of software engineering concerns the design of system interfaces that minimize cognitive load of users (Oviatt 2006).

The **data reliability-oriented understanding** of human-centered AI refers to existing deficits of the AI technology in order to provide a reliable tool in individual decision making. Criteria of human-centered AI referring to this perspective are reliability, validity, fairness and explainability. Due to the complex nature of some machine learning algorithms, i.e. deep learning algorithms, it is important that the scope, type and quality of data used as an input are visible. Further, opacity of algorithmic output and decisions must be avoided (Gal et al. 2020). In this regard, the *explainability* of AI outputs is particularly important for user acceptance (Deng 2018) but most challenging since deep neural networks provide more powerful outputs the more complex their hidden structure is (Rai 2020). Two technical approaches for reaching explainability are "intrinsic interpretability" which aims at developing less complex, self-explanatory models that can be instantly interpreted by humans or "post-hoc interpretability methods" that aim at explaining very complex models by describing the logic through similar less complex models (Bauer et al. 2021). Further, explainability can be aimed at enabling a global understanding of the models (its structures, assumptions, parameters) or local interpretations (contribution of input features to output; Bauer et al. 2021). The basic approach is to systematically analyze the hidden structures of the neural networks using suitable tools in such a way that, in addition to the actual outputs in terms of decision support, further information are provided to the users that supports and empowers them to understand the decision criteria of the model. Human-centricity is reached when a user can recognize biases or quickly detect causes for certain misjudgments of the model (Meske et al. 2020). The disclosure and explanation of decision criteria enable humans to test for possible violations against commonly agreed upon (and potentially legally anchored) fairness criteria like avoiding discrimination. The disclosure of decision criteria gives the human information about the reliability of the AI-based decision results and may lead to a trustful relationship. In this context, explainability research focusses on how humans respond to different types of explanations (e.g. intuitiveness, usability; Bauer et al. 2021). Explainable AI is thus considered a multidimensional challenge, as it involves not only technical trade-offs between prediction accuracy and transparency of results but also political and societal efforts (Beaudouin et al. 2020).

The **protection-oriented understanding** of human-centered AI focuses on the physical and mental integrity of the human being. Job design and technology development follow the principle of providing work contexts with tasks that are executable, harmless and safe, tolerable and personality enhancing (Hacker/Richter 1980). AI applications may be implemented for the reason of protecting workers from possible risky and harmful working conditions (Giusti et al. 2018). AI applications in mobile robots can prevent humans from working in environments with e.g. high radiation or other forms of contamination. A mobile robot can carry a load that would be too heavy to carry by humans. An AI expert of DHL explains (Port of Rotterdam 2021) that robots can take over hazardous tasks from humans, don't mind monotonous, repetitive work and can carry more load. The Port of Rotterdam also uses AI-based Automated Guided Vehicles which take care of transport of containers to the depot. They are unmanned, fully automated and recognize by themselves when their battery is almost empty. They then drive to the battery exchange station and receive a new battery from a robot. The core issue of the protection-oriented perspective is to free employees from heavy loads, possible harm and intolerable working demands. Human wellbeing is in the center of the optimization.

Taking the burden off human workers is the first step, but protection-orientation does not refer solely to the release from health damages but also from bad work design with risks involved (e.g. due to skill decay, dissatisfaction and frustration, no commitment and fear of social isolation) of the work portions that remain for the human worker. These aspects are represented in the model of SMART work design (Parker/Grote 2020). Human-centered AI can contribute to these aspects by providing motivating work settings that strengthen human agency and are meaningful and challenging for all humans involved.

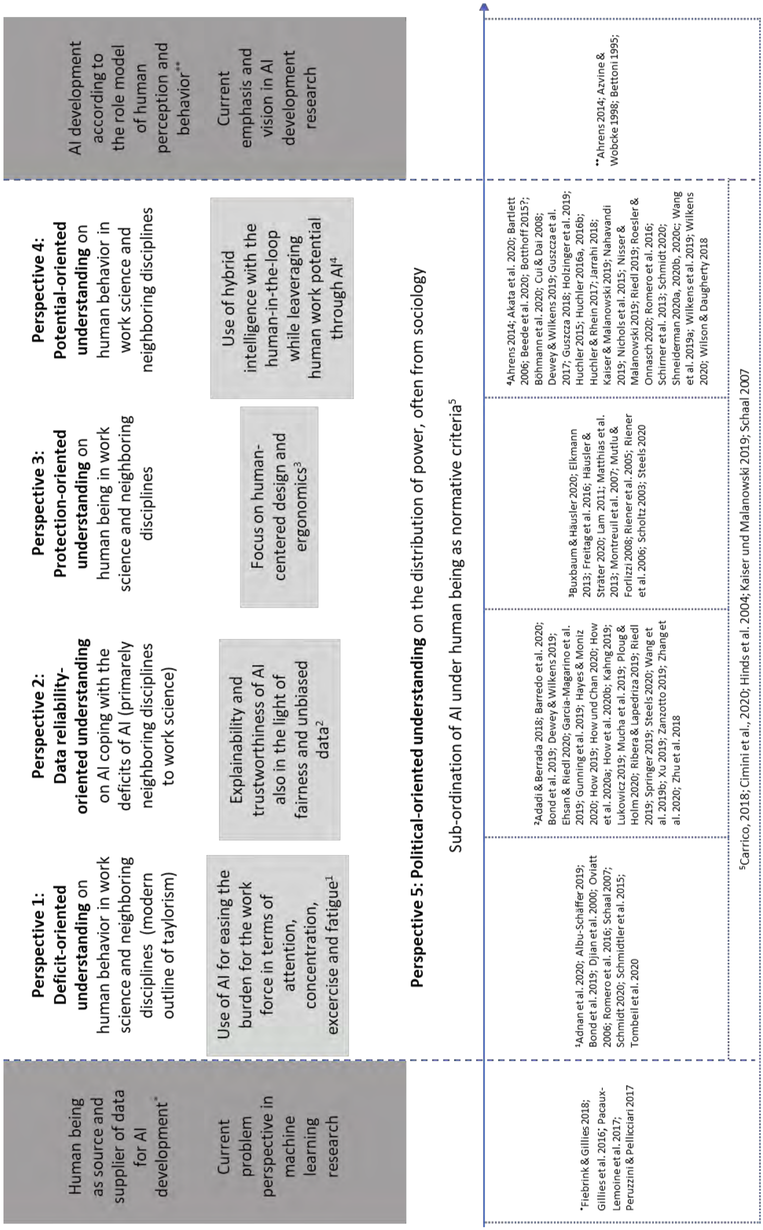

Figure 3: Five perspectives on the meaning of human-centered AI
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The **potential-oriented understanding** of human-centered AI gives emphasis to a so far unexploited potential of leveraging individual abilities while developing work systems with hybrid intelligence bringing together individual intelligence with AI in a collaborative manner. There is a strong belief in better outcomes for individual and organizational development as well as task proficiency at the same time. Human-centered AI thus means that technology is utilized in a way that is beneficial for the *competence development* and learning of users (Vladova et al. 2019). Whether competences can be enhanced through AI or even reduced is a matter of socio-technical system design (Wilkens et al. 2019). Another concern within the potential-oriented understanding is *work design based on strengths of humans and technology*. Human-centricity is reached by creating work systems where humans and technology can "complement each other through human-computer cooperation" (Cui/Dai 2008). In that sense, the aspired goal is to develop AI solutions which can also be described as human-AI teaming, as active and interdependent collaborations between humans and AI to achieve a common goal (O'Neill et al. 2020). This includes opportunities for communication between humans and AI, mutual support, shared understanding of the situation or a mutual recognition of intentions (Chen et al. 2018). Another important focus within the potential-oriented understanding is on work systems that benefit from *distributed intelligence* (Fischer 2001; Cobb 1998).

The **political-oriented understanding** of human-centered AI gives emphasis to the distribution of power between AI and those who use AI in the work context. The main concern in this regard is that AI remains under human control. This perspective is applied to research on robot design that ensures human responsibility (Hinds et al. 2004). Other research raises awareness for social aspects, when an increasing number of robots with different roles is used in socio-technical systems in the manufacturing industry (Moniz/Krings 2016). The main concern of this perspective is establishing *regulation for subordinating technology under individual control.*

Based on these perspectives, human-centricity of AI solutions are reflected in various related concerns. These concerns go beyond the consideration of encompassing integrations of human and artificial intelligence, which for example the "AI management framework" would consider the highest level of maturity (Lichtenthaler 2020). Rather, the design and implementation of human-centered AI solutions implies to consider technological (e.g. securing reliability), human (e.g. ensuring protection) and organizational (e.g. reducing deficits and enhancing potential) requirements.

It becomes obvious from the overview that there are many questions how to relate these criteria to each other and that some of them even might contradict to each other especially in the field of how to manage control. This is why we try to gain a deeper understanding from selected use cases which allow to better understand how to exploit the potential of AI in a human-centered manner.

Table 1 gives a brief summary of the specific concerns of each of the five perspectives of human-centered AI.

Perspective of human-centered AI	**Concerns of the perspective**
Deficit-oriented	Failure control function of the technology
Data reliability-oriented	Disclosure of decision criteria by AI System Testing for fairness and reliability by human worker Aiming at a transparent outputs for the user
Protection-oriented	Ensuring that work is executable, harmless and safe Enabling work that is stimulating and personality enhancing
Potential-oriented	Enabling competence development Work design based on strengths of humans and technology Work systems with active and interdependent collaborations between humans and AI (distributed intelligence)
Political-oriented	Regulation for subordinating technology under individual control

Table 1: List of concerns for the five perspectives of human-centered AI

3. Qualitative case descriptions

3.1 Insights from practice - what do we learn from good and bad practices?

In this paragraph we introduce selected cases with reference to the five perspectives of human-centered AI in order to better understand how to indicate maturity and how to relate certain criteria to each other. The case selection follows the principle to address those fields where AI enters the workplace and unfolds a specific function such as enhancing precision, supporting quality control or decision making, facilitating learning or carrying heavy loads. In this regard there are similarities between workplaces from different industries and sectors. This is why the case selection goes beyond manufacturing and also includes the healthcare or training sector. The descriptions are derived from interview studies or daily exchange with practitioners respectively from case descriptions in the literature.

Example 1: AI-based diagnosis in radiology

There is an increasing emphasis on precision and quality control enhancement in the field of medicine, especially radiology (Thrall et al. 2018), where AI is in use for diagnosis and treatment suggestions with feedback-loops between therapy and diagnosis. There are similar developments in AI-based imaging in steel production but the evaluation of the consequences for job design is more advanced in medicine and thus in the focus of the exemplification. Interview studies with radiologists show that physicians especially appreciate AI as a tool that allows them to get rid of monotonous tasks and to gain better output in decision making processes:

"I believe at some point the attention threshold is simply no longer the same after five hours as it was after the first hour. And I think that's what it's good for. If a machine learning program runs in the background like a safety net and really displays "So, I find this striking, don't you want to look at it again?" Or perhaps during the shifts in the hospital, the radiologists are not on site 24 hours a day, that the clinicians in the emergency department justify their images themselves and make decisions, and if they are young colleagues, then they simply haven't seen so many images yet, and I believe that machine learning can be a good support as a safety measure." (see interview study from Wilkens/Langholf 2021).

"Where I can also imagine it well is, for example, when they do a staging examination of the lungs. There, it's often just a matter of counting the metastases and that's not very exciting for us and more of a hard work. So I can also imagine that the AI will do it in the future. Yes, I think the risks are just, above all, that the algorithms are not so good, because they are only tested on their data set with which the algorithm is developed. It actually has to be fed more continuously in order to be as usable as possible." (see interview study from Wilkens/Langholf 2021).

Radiologists make also clear that they first expect the trustworthiness of AI as a prerequisite before making use of it – this might be especially relevant when there is a high responsibility for human life:

"We know that from many research projects that students sometimes do the annotation because it's inexpensive. But of cause this is problematic. The radiologist should actually do the annotation so that there is a well performing AI in the end. And this is something I often see: When the algorithm is written poorly the product will be poor as well. Then it won't be of real use in the hospital after all." (see interview study from Wilkens/Langholf 2021).

According to this case the failure control function of technology for compensating individual deficits or failure is highly appreciated as an issue of enhancing the individual expertise. There is no fear that the individual status could suffer but quite the opposite that the individual expert status could benefit from better decision making. However, the prerequisite and necessary condition for making use of AI tools is its reliability and the elaboration on trustworthiness. Otherwise there would be no basis for enhancing expertise.

Example 2: Radiographers and speech therapists unlikely working with the AI machine

There are job designs for human-computer-interaction very close to the described workplace of radiologists but however lead to different perceptions and attributions from the employees. As a typical radiographer working at the same place as the radiologists argues:

"The computer takes everything off our hands, it already places everything and I actually only have to say okay. [...] I see [...] that I am becoming more dispensable." (see interview study from Wilkens/Langholf 2021).

In a similar manner there was the idea of AI developers to introduce an AI-based logopedic training system. With the AI training system the patients should be able to practice independently at home. The AI system was able to give individual feedback and correct pronunciation. The goal was to allow patients to continue practicing between sessions with a speech therapist and between face-to-face meetings and thus make faster progress. In that way, the AI solution could be used to compensate for a lack of resources (time, availability) of the speech therapists. Even though one might assume that the advantages for the patients are obvious – as the system can be considered as a supportive training aid - the AI-based speech therapy training system was not in use by the speech therapists. They were in concern that the AI system would replace them one day and this was weighted much higher than the possible benefit for patients.

These examples show that in these cases the AI users in the workplace are afraid of losing expertise and are not involved when considering future perspectives of organizational development including individual job profiles. This fear of losing expertise can also be expected for tasks profiles in industry which are based on vocational training. It becomes obvious from these case descriptions that regulations for subordinating technology under individual control define a necessary condition for otherwise less involved employees. In addition to the trustworthiness of AI this tends to be another prerequisite in order to make use of AI in the workplace.

Example 3: Experts in quality management searching for a new role concept

A petrochemical company introduces an AI system that analyzes photographs made by a drone that show welding seams of the pipes of a chemical plant. Weldings seams need to be checked for possible porous and cracked parts. In the past, an expert took the photos with a camera and analyzed them regarding these porous and cracked parts. The task requires extensive vocational training and certified expertise in the quality control of the pipes welding seams. Previously, the job fulfilled the criteria of human-centered work design in terms of identity, agency and satisfaction. After the implementation of the AI based visual quality inspection, there is the risk assigning those aspects of the former well designed task. If the AI would only ask the human in cases of inconclusiveness the human would be in the role of supervising the AI over a longer period of the day, interrupted by some troubleshooting tasks, in the case that the AI is helpless. This kind of implementation is violating the criteria of identity, agency and satisfaction.

It becomes obvious from the example that the integration of AI needs to be combined with a role development perspective for the employees in order to fulfill workers' needs with respect to agency and stimulating work that leads to the perception of mastery.

Example 4: AI-based tools for individual competence development and career planning

A well-known and sophisticated tool for AI-based individual competency management and career development is the example of the IBM Watson Career Coach (see Guenole/Feinzig 2018). The general idea is that the „Watson Career Coach", as a trusted AI advisor, is consulted by employees for career advice. The organization thus requires competence- and career-specific data of company/competence profiles as well as job profiles, information on how long a person has been with the company and also in a specific position, comparison with data of other job holders in the same position. The company-specific trained AI based career coach "Watson" learns what moves and interests the employees in the company. Subsequently, the career coach simulates the next career step of each employee. In contrast to human resource personnel or supervisors, Watson is able to integrate big data information – arguably with less bias – and might thus provide employees with more objective and reliable career advice that has more predictive value than intuitive predictions.

The capacity of AI to enhance and support individual potentials becomes obvious from this example. Yet, it is still far from practical application as missing data quality is as severe as in the field of hospitals as described in the first example. This is especially the case because companies' practices in career development were not free from discrimination in the past. Available data do not necessarily lead to fair practices in future (violating the criterion of reliability-oriented AI). This means that the trustworthiness of AI and the disclosure of decision criteria is a key prerequisite also for enhancing potential.

3.2 Blueprint for a maturity model of human-centered AI

Our aim is to stress that due to the five different perspectives of human-centricity, maturity is not achieved by fulfilling each and every one of the criteria but by establishing configurations of these criteria that represent a balanced and context-related approach. The introduced case descriptions underline that it is in principle more than one criterion that matters but that a context related selection and focus tends to be helpful at the same time. A maturity model is a suitable guideline for the implementation process if it allows to monitor the most important firm specific criteria without neglecting complexity.

The first outcome from the case description is that the trustworthiness of AI and the disclosure of decision making criteria are necessary conditions for integrating AI in job designs with human-computer interaction. This became obvious when radiologists explained that they otherwise would not make use of the technology because they have to take the responsibility for the therapy. It became also obvious from the example of the career coach. If the individual development depends on

AI-based support, the individual needs to be convinced that there is no hidden discrimination due to faulty algorithms. Trustworthiness can result from the visibility of the input (scope, type and quality of data) and the explainability of the output/ decisions. It equally matters for fields where AI compensates human deficits and enhances individual competence development.

The second outcome is that the integration of AI creates a vacuum for employees' upward or downward development especially in fields with high expertise and proficiency in a non-academic manner but based on vocational training. This became obvious when radiographers or speech therapists expressed their concern of losing their expert status. This is why there is a need for regulation which takes into consideration the individual involvement in workplace development including the moderation of a role development process. This is a further necessary condition for a human-centered way of integrating AI in the workplace.

The third outcome related to the protection-oriented perspective is that job design should not only include criteria where AI can prevent from physical and mental harm – this defines an overall necessary condition for job design – but also consider criteria how AI can contribute to a personality supportive job design in terms of identity, agency and satisfaction. This became obvious from the third example referring to quality control in welding seems. The individual job profile needs to be coherent and integrative and cannot be reduced to troubleshooting functions. This supposed to describe a sufficient condition.

The fourth outcome is that there are further dimensions of a human-centered AI that can be classified as sufficient conditions for the use of technology. These dimensions are not necessarily interrelated but define alternative ways of using AI for human-computer interaction. One direction was just mentioned in the field of personality development in quality control. Two other directions result from the deficit-oriented and the potential-oriented perspective. There are job profiles, e.g. for physicians in radiology, where the compensation of failure is appreciated with respect to the quality of output and the attribution of individual expertise. As the first example from radiology explored it was the compensation of deficits which was considered as basis for enhancing the expert role of radiologists. There are other job profiles where the enhancement of individual expertise through the use of AI can be considered as beneficial for the proficiency of output and the individual development perspective, e.g in AI-based career development. Table 2 summarizes these criteria and relates them to different maturity levels. The blueprint specifies criteria for all five dimensions that are based on the perspectives of human-centered AI. In addition, all criteria are organized in a logical hierarchical order indicating different levels of maturity.

According to the examples chosen in this outline, there is some evidence that it depends on the context which criteria are more likely in the focus. It might be a combination of regulation and compensation of deficits together with personality enhancing job design especially in manufacturing but a combination of trustworthiness and potential-enhancement in the field of services.

	Dimension	Criteria (how to reach)
Necessary conditions	Trustworthiness and explainability of AI	T1: Availability of big data T2: Cleanup of data (scope, type and quality of data) T3: Explainability of decisions (disclosure of data structure in decision support) T4: Integration of (implicit) user-domain knowledge in data management
	Regulation (Degree of regulation for subordinating technology under individual control)	R1: AI users informed about future workplace perspectives R2: Users involved in workplace development R3: Role development concept specified R4: Role development concept ratified in labor regulation
	Protecting individuals	P1: AI detects if criteria of tolerable work (executable, harmless, safe) are hazarded P2: AI ensures that criteria of tolerable work can be fulfilled
Sufficient conditions	Personality enhancing	P3: AI enhances personality-supportive job design (identity, agency and satisfaction) P4: AI enhances social job design (stimulating, mastery and agency enhancing)
	Compensating deficits	C1: AI detects failure automatically C2: AI informs the user C3: AI prevents from repeating failure C4: AI initiates feedback-loops on system level
	Enhancing potential	E1: AI provides impulses to individual competence development E2: AI integrates human intelligence in critical processes E3: AI creates a working system with collaborating humans and AI (distributed intelligence).

Table 2. Blueprint: Dimensions and criteria for human-centered AI maturity

To account for this context dependency, the blueprint can be understood as a fan model (Figure 4). The model proposes a dynamic, context-sensitive implementation of human-centered AI. The rotatable outer circle implies that the focal sufficient conditions of human-centered AI can be different depending on the specific context of AI implementation. The dashed lines symbolize the foldable nature of the conditions, which, like a fan, allow to map a context-appropriate configuration of conditions for human-centered AI.

The advantage of the introduced model is that it allows to integrate context factors with respect to the concrete workplace design and avoids complexity where unnecessary for the implementation journey. In this regard our approach reflects on the sociomateriality (Orlikowski/Scott 2008) and goes beyond the models introduced in paragraph 2.1. The blueprint of the fan model indicates that there are certain ways how to refer to the interrelatedness between technology and human beings and that this is crucial for monitoring the human-centricity. To further illustrate this consideration we point to two specific cases outlined earlier and show how the fan model can be applied to these specific contexts.

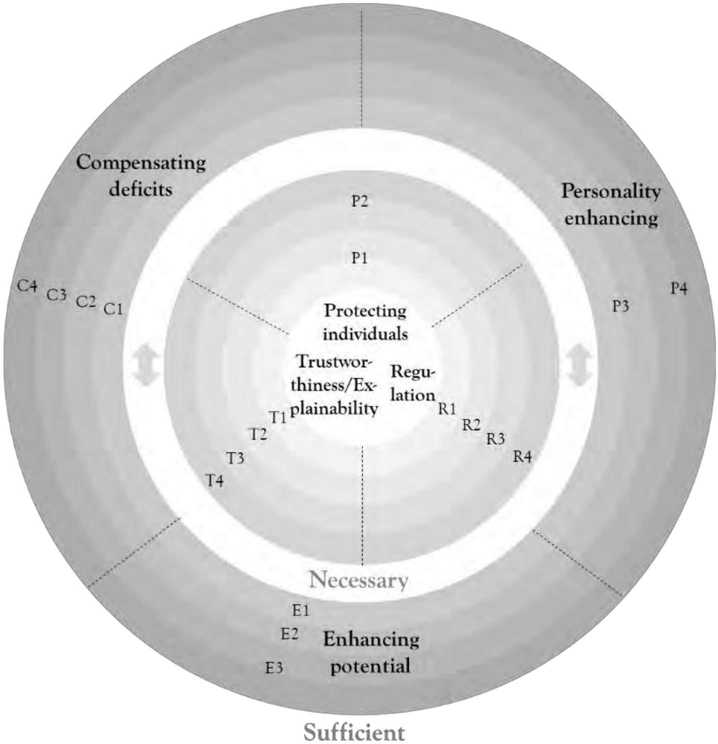

Figure 4: Blueprint: fan model for maturity in human-centered AI implementation

The radiologists (Example 1) had a very specific concept of AI in their work system due to their background and training. The prior role of humans was taken for granted and there was no concern about missing a personality-related job design but trustworthiness of AI was a crucial point for them to make use of the technology. This is why it defines a dominant necessary condition. Another key concern of radiologists was that the technology eliminates human error and relieves them of monotonous work. This concern is related to the deficit-compensating function of AI which is considered as job design making the expert role of radiologists even stronger (see Figure 5, left side).

From Example 2, the speech therapy system, it was not the trustworthiness of the technology which was in concern but the remaining vacuum with respect to the own job profile. This is why the regulation with respect to a personality-enhancing job profile turned out to be particularly important criteria which defines a necessary condition which the personality-enhancing components themselves define a sufficient condition (see Figure 5, right side).

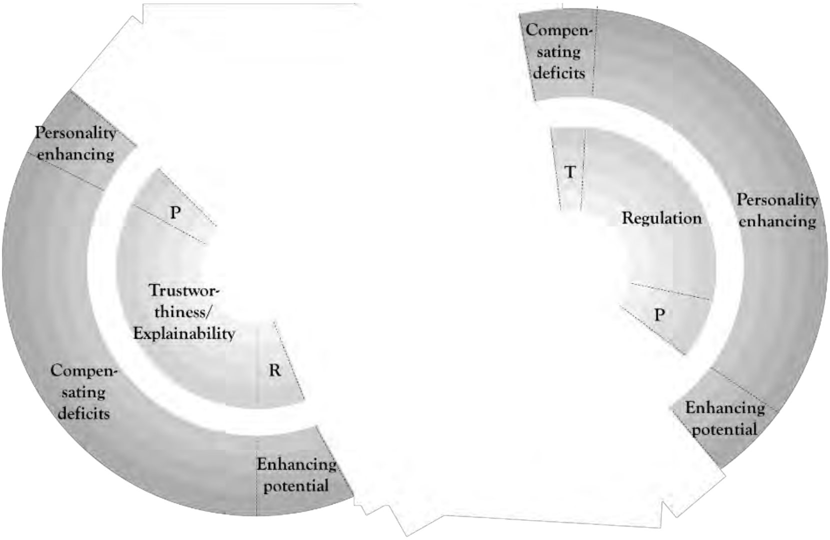

Figure 5: Fan model applied to radiologists (Example 1, left side) and speech therapists (Example 2, right side)

4. Summary, Outlook and Limitations

In this paper we suggested a blueprint for AI implementation in the workplace which includes two aspects. It takes into consideration certain definitions and perspectives of what human-centered AI means and gives evidence to these perspectives in a context-specific manner. This is why the model includes complexity on the one hand side but encourages to reduce this complexity for a context-specific implementation journey. Hence, the blueprint works as a fan model.

The blueprint suggests different maturity levels and how to operationalize them for each of the five dimension included either as a necessary or as a sufficient condition. Whether this operationalization is coherent and also balanced with respect to the distances between the maturity levels needs to be validated in a simulation environment and by the help of a quantitative test design in future research. An important next step could be laboratory studies e.g. with radiologists or students from medical school who have to make decisions by the help of AI-based imaging, how they reflect on the decision support, how they evaluate the explainability and how they estimate their expert role etc. This is also important in order to learn more about the relationship and interrelatedness between the proposed maturity criteria of successful transformation. Moreover, the validation process can help to identify criteria which might have been neglected so far. But the most interesting and promising part of the empirical exploration is to find out whether there are clusters and core combinations with high relevance for certain fields of AI implementation or combinations of criteria which would contradict each other.

Another most important prerequisite for initiating empirical testing is the question whether the fan model idea has an intuitive plausibility for stakeholders who are involved in the AI implementation process. The floor for this discourse is now open.

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Developing competencies for collaborative work settings in a virtual simulation laboratory

Training approach and performance measurement

Annabelle Beyer, Murat Keskin, Uta Wilkens

1. Introduction and problem definition

The transformation of the working environment towards industry 4.0 is accompanied by an increase of automation and flexibilization of work processes, leading to a merge of manufacturing and knowledge work (Spath et al. 2013). Furthermore, new digital data driven process technologies are incorporated into work settings, resulting in an increase of overall work complexity (Bauernhansl 2017). Employees are confronted with new task profiles with respect to process regulation and market development. Work becomes more interconnected while process controlling, organizing and planning aspects come into focus (Hirsch-Kreinsen 2017). These changes are affecting the shop floor as well as the management level, leading to the reorganisation of work for all business entities (Wilkens/Hermann 2016). In order to meet these new challenges, it is necessary for employees to develop critical competencies for Industry 4.0 (Teichmann et al. 2020).

These critical competencies for coping with Industry 4.0 work environments have already been specified and empirically investigated in several studies in terms of coping with complexity, multiple role development, collaboration and continuous reflection-on-action within (remote) work settings (Petzold/Bullinger-Hoffman 2017; Wilkens et al. 2017; Voigt et al. 2015; Spath et al. 2013), process oriented thinking and remodelling the use and management of knowledge (Gronau 2020) as well as digital competencies (Süße et al. 2018).

With respect to competence development, various training approaches related to these competencies have been developed such as learning factories, business simulations and serious games (for an overview see Sudhoff et al. 2020; Teichmann et al. 2020; Wilkens et al. 2020; Nyhuis et al. 2019; Reuter et al. 2017; Meier et al. 2015; Voigt et al. 2015). These approaches address different operational levels in terms of process knowledge or business skills. Besides creating appropriate settings, it is important that these training activities are accompanied by suitable performance measurements to ensure a purposeful development of competencies. The issue of performance measurement can more likely be integrated in production-related competence development. Transferring this to appropriate training

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settings referring to new business environments in collaborative ecosystems is a challenging task, as outputs are not always clearly delineated and performance cannot easily be related to specific action and becomes visible on the overall system level.

The present article addresses this challenge by summarizing current research results regarding competencies, deemed important for industry 4.0 and related training approaches. Subsequently we introduce a critical evaluation and reflection of a digital simulation laboratory and an accompanying performance measurement for collaborative work settings in industry 4.0. The aim is to find a suitable design for evaluating training scenarios with an emphasis on work demands in collaborative ecosystems.

2. State of the art: Which competencies matter in Industry 4.0 work settings and how to train them

To gain a better understanding of co-existing approaches regarding competency conceptualizations and training methods in the context of industry 4.0, it is first of all necessary to develop a deeper understanding of different work settings within industry 4.0 and its employee demands. The shift towards Industry 4.0 does not only affect existing manufacturing processes and methods, but also leads to the evolvement of dynamic digital ecosystems (Hirsch-Kreinsen et al. 2019). Based upon this argument of digitization and accompanying servitization, there are two dimensions describing the transition journey towards industry 4.0, the back-end and the front-end digitalization (Coreynen et al. 2017). Back-end digitalization describes the manufacturer's production operations with the goal of optimizing processes through automation and digital integration. Front-end digitalization describes the interaction with customers, driven by the manufacturer’s aspiration and need to provide customer-centric solutions in order to gain competitive advantages (Coreynen et al. 2017).

Across all perspectives, competence can first be defined as the capacity of social actors to develop problem-solving skills in situations that can be characterised by both, their complexity as well as a certain degree of uncertainty. These are based on self-organised actions which ultimately brings innovation forward (Wilkens et al. 2015). Competencies, unlike qualifications, thereby become visible in the form of performance through and within related actions. Based upon the systematization of work perspectives according to Coreynen et al. (2017), the assessment of which competencies are particularly important in industry 4.0 work settings and also the accompanying training approaches can be differentiated regarding their addressed context. Table 1 gives a brief overview of existing competency conceptualizations and corresponding learning approaches and the respective work context

	Wilkens et al. (2017)	Gronau et al. (2017a; 2017b)	Prinz et al. (2016) based upon Dombrowski et al. (2014)
Generic competencies	Coping with complexity Self-reflection Combination Collaboration	Process Competence Organization Competence Interaction Competence	Technical and methodological Competence Social Competence Personal-Competence
Specified for Industry 4.0	Multiple role concept Coping with complexity Reflexive team-based learning	Organizing machines, work pieces and information Process knowledge Flexible Cooperation and Collaboration	Problem solving and supervision Widely spread expertise Judgement Interdisciplinary Personal responsibility Holistic thinking Ability of communication Adaptability
Addressed context	Collaborative team settings in digital ecosystems	Industrial flow processes in the context of the industrial internet of things	Real world manufacturing and production processes
Related training approach	IPSS Business Simulation	IoT-Laboratory	LPS Learning Factory

Table 1: Overview of existing competence conceptualizations and accompanying training approaches

The comparison of the selected concepts underlines that the different approaches rather complement than contradict each other. The training approaches address different work settings either more front-end or more back-end related. Bringing them together would lead to a comprehensive approach.

It is apparent that concepts focusing on the back-end are primarily centred on aspects of process and organisational competence, since these are mainly focused on production processes. Competency development for back-end processes usually takes place in learning factories, e.g. in the IoT-Laboratory and LPS (Gronau et al. 2017a; 2017b; Prinz et al. 2016). Recent studies show that in Germany alone, there are currently 30 learning factories that focus on competence transfer in the back-end by addressing challenges such as the improvement of production processes, digitization, product management and automation of processes, to name only a few (Sudhoff et al. 2020). Learning factories allow participants to directly act on applications to test work processes and thereby support competence development through observations, reflections but also generalizations (Tisch et al. 2013; Tisch/Metternich 2017). Based upon the presented competence perceptions (Table 1), different learning objectives can be derived, for example becoming comfortable in the use of new methods and technologies in production and adapting to new application contexts (Prinz et al., 2016). These learning objectives create a base for further applications in terms of competency development.

When considering concepts that focus on the front-end, a shift occurs with regard to the consideration of important competencies. Regarding front-end work settings, employees have to be able to work within heterogeneous teams and combine different knowledge sets in order to create customer-centred problem solutions, which is why the set of competencies deemed most important is leaning towards team interaction abilities (Mänz et al. 2013; Wilkens et al. 2017). Regarding the identified competency facets by Wilkens et al. (2017) a business simulation was introduced for a specific PSS working environment, mainly focussing on elements such as cooperation and team work within a digital learning environment (Voigt et al. 2015; Cibat et al. 2017). Similar to the back-end approaches, the simulation is characterised by the depiction of concrete work processes. Comparing to existing back-end competency development approaches it thus becomes apparent, that the landscape of existing training methods concerning the front-end is rather small.

When it comes to performance measurement the back-end approaches are more advanced in providing a measurement approach which is directly integrated in the training scenario with respect to time, resource saving or quality management. These can be monitored using indicators such as process cycle times or general output measurements, e. g. process improvements, fulfilment of customer requirements or other key performance indicators (Prinz et al. 2016). Concerning the presented front-end training approach, the performance measurement occurs through the recording and evaluation of participants' actions (Süße et al. 2017). The measurement of performance within front-end settings cannot directly be linked to key figures as it is possible in the back-end training approaches, since it only becomes visible within the entire socio-technical system. Thus, making specific measurements more difficult.

In the following, a digital simulation laboratory and accompanying performance measurement approach, addressing the front-end perspective of industry 4.0 is presented. The aim of this simulation laboratory is to train interdisciplinary teams in coping with the demands of front-end working contexts and simultaneously identify performance indicators for this work environments.

3. Introduction of a simulation laboratory for collaborative work settings

The digital simulation laboratory "Collaboration Space" was established in a public-private partnership between the Ruhr-University Bochum and the local start-up Think Square. It was first put into operation in September 2020 as part of an interdisciplinary seminar. The scenarios within the laboratory are aligned to an escape game approach. The overall setting represents the work context of Industry 4.0 in a gamified way, including corresponding challenges as for instance the processing and systematic usage of large quantities of information and the achievement of solutions only with the help of joint collaborative (digital) work. According to the systematization introduced in chapter 2, the simulation laboratory therefore represents a competence development approach that addresses the front-end perspective of industry 4.0.

There are several target groups invited to the laboratory training, participants of graduate seminars as well as people from professional environments in post-graduate trainings. Since its first introduction, the simulation lab has been integrated into a wide variety of seminar settings, each with the aim of confronting interdisciplinary student teams with challenges of digital collaboration in the context of Industry 4.0 on an abstract level. So far, the simulation lab has primarily been tested with heterogeneous student groups consisting of, among others, majors in master degrees of economics, chemistry, biochemistry, business psychology and educational science as well as part-time students.

The different scenarios are embedded in an online game interface. The teams are provided with a protected environment in which they can test out different actions, without having to be concerned about consequences of wrong decisions, although these consequences are experienced in an abstract manner. In teams of three to six members, the participants assume the role of an interdisciplinary team of laboratory technicians and managers who have been commissioned with the overall goal to develop a water disinfectant. Followed by a hacker attack, the team must get access to critical data and formulas for the imminent market launch of the product. To fulfil this task, the teams work through three simulation scenarios (see illustration 1), which are based on the competence facets according to Wilkens et al. (2017).

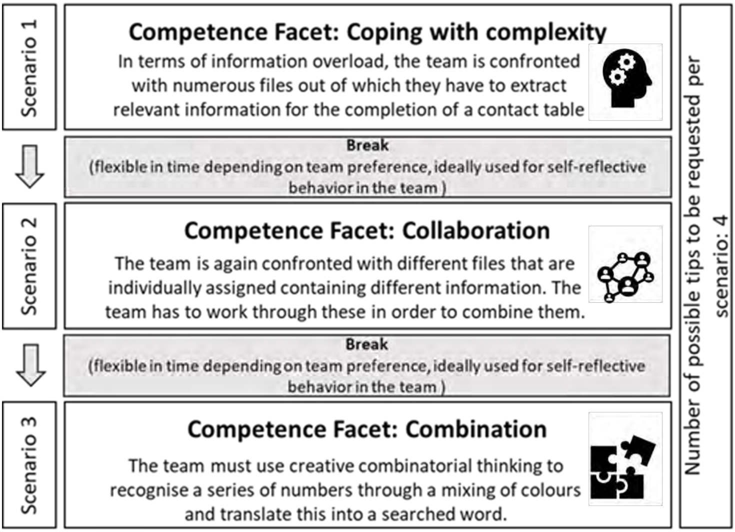

Illustration 1: Scenarios of the simulation laboratory "Collaboration Space"

The learning levels build on each other to create an overall game flow setting. Each of these scenarios place a particular competence facet in the centre of interest. One scenario is addressing the competency facet of coping with complexity, followed by one scenario each focusing on collaboration and combination skills. The competence facet of self-reflection is not assigned an explicit sub-scenario, but the teams are free to reflect on the group's performance in the short breaks between the individual scenarios. This allows the groups to reflect on action routines and adjust them if necessary. The run through the simulation happens within the game flow and does not require any interaction with the game master during the whole gameplay. Once the solution for the simulation sequence has been entered by all participants, the next scenario opens up.

The simulation laboratory is accompanied by a measurement approach specifically adapted to the scenarios. The measurement approach builds on research findings from the fields of game-based learning (Pan, Lo & Neustaedter, 2017) and competence measurement methods (Wilkens et al., 2017). In addition, formative factors as well as moderators and performance outputs are measured (see Figure 2).

The formative factors are based on the individual competencies of the team members, which are collected via self-assessment questionnaires prior to the beginning of the simulation. The survey is based on the competency facets of complexity management, collaboration, creative problem solving and self-reflection according to Wilkens et al. (2017), which were also decisive for the scenario design and thus run congruently with the game scenarios. The existing set of variables is supplemented by the competence in activity and action factor according to Heyse & Erpenbeck (2009). The individual competence self-assessment is based on a total of 30 items, which have to be rated on a 5-point Likert scale.

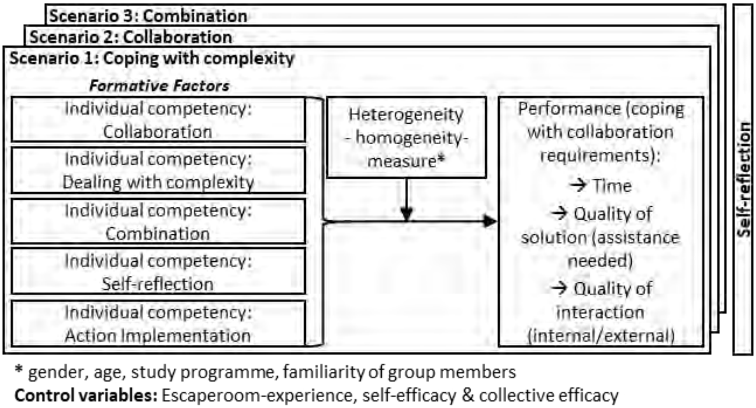

Illustration 2: Design of analysis

In addition to the above-mentioned competence facets, moderator variables were gathered to obtain information about the heterogeneity or homogeneity within the groups. In addition to data with regard to age, gender and study programme composition of the team, it is also ascertained whether the group members are familiar with each other and have already worked together. As control variables, the collective and individual efficacy expectations according to Schwarzer & Jerusalem (1999) as well as previous escape room experiences of the team members are surveyed.

The measurement of performance, which can essentially be summarised as dealing with the hurdles of (digital) collaboration in the working environment of Industry 4.0, is conducted using three different output factors, described in the following.

1. *Time*

   The time that the teams need per scenario is measured to provide information about the partial performance, as well as the overall performance. The time limit per scenario is 25 minutes for a performance that would be considered as optimum.

2. *Quality*

   For each scenario, the teams can request a total of four hints. These hints are predefined and standardised to ensure comparability between the teams. If the teams were able to solve the riddles without any support in terms of requested hints, the performance is categorized as optimum. The quality of the achieved solution decreases gradually with the number of used/requested hints.

3. *Team atmosphere (sustainability of team setting)*

   The third performance measure is the perceived team atmosphere (also called sustainability of team setting), which is assessed post-simulation, using self-assessment surveys completed by each team member as well as an external observation survey completed by the game master. The surveys are based on the items of mutual support and general communication according to Lechler (2001) as well as supplementary variables on goal-oriented communication. A high score is assumed to indicate that team members will collaborate with each other also in the future.

While the team atmosphere refers to the entire game, the output factors of time and quality in form of requested tips allow deeper insights into the sequential performance of the team.

The present evaluation is based on a sample size of 19 groups which participated in both the simulation and the surveys as part of different seminar contexts. This means that the presented evaluation is a work in progress and has to rely on a more qualitative comparison between high, medium and low performing groups. For the distinction of these groups we primarily referred to the time needed by the teams to complete the simulation. Given that the optimum time per simulation sequence is set to be 25 minutes, the high performer category includes every group that was able to complete the simulation within a total of 75 minutes. The category of medium performers includes all groups that took 76 up to 105 minutes and the low performer category includes all groups that took more than 106 minutes. For each group, the individual competency assessment results were aggregated into a competency index, likewise to the sustainability assessment results, the moderators and the control variables.

4. Preliminary Findings

The preliminary results, presented in table 2, show that out of the 19 groups, nine groups fall into the high performer category, while six groups can be categorized as medium performers and four as low performers, regarding their average time needed to complete the simulation.

	High Performer	Medium Performer	Low Performer
Team specifics			
Teams	9	6	4
Average Team Size	4,3	4,5	5
Performance Measurement (mean)			
Time	01:06:04	01:30:04	01:51:11
Quality (hints requested)	0,1111	0,3333	2
Sustainability Self	4,6119	4,0688	4,1678
Sustainability Ext.	4,3024	4,1944	3,8055
Competencies (mean & distribution)			
Overall Competence	3,7134	3,4286	3,6872
Distribution	0,355025	0,46326	0,2959
Cooperation	4,07977	3,77881	4,14444
Distribution	0,44441	0,66580	0,44166
Coping w. Comp.	3,0667	2,9167	3,1700
Distribution	0,55693	0,32552	0,36288
Reflection	3,5795	3,4769	3,6500
Distribution	0,50009	0,59887	0,57993
Action Implement.	3,9230	3,4872	3,6917
Distribution	0,45055	0,79850	0,51943
Creative Probl. Sol.	3,9179	3,5111	3,7800
Distribution	0,57256	0,70456	0,44438
Moderator variables			
Age range	19-49	20-31	22-34
Gender distribution	38,5% male	37% male	15% male
	61,5% female	63% female	85% female
Study programme	64,1% business rel.	66,7% business rel.	35% business rel.
	12,8% part-time	7% part-time	50% part-time
	23,1% other	25,8% other	15% other
Familiarity of team members	59% knew all	33,3% knew all	25% knew all
	15,4% knew some	25,9% knew some	55% knew some
	25,6% knew none	40,7% knew none	20% knew none
Relationship between team members	23,1% friendship	3,7% friendship	15% friendship
	53,8% collegial	40,7% collegial	50% collegial
	12,8% cursory	22,2% cursory	25% cursory
	23,1% n.a.	33,3% n.a.	10% n.a.
Experience in working together with the team members	15,4% yes	7,4% yes	20% yes
	41% no	63% no	40% no
	43,6% partially	29,6% partially	40% partially
Control variables (mean)			
Self-Efficacy	3,6267	3,2482	3,5327
Collective Efficacy	4,1949	3,9037	4,04
Escape Game Exp.	2,72	1,1	0,8

Table 2: Preliminary results

With respect to the performance quality in terms of requested hints in the overall simulation it is noticeable, that the number of hints required increases with a descending performance regarding the time. This effect can probably be attributed to the duration of the simulation, as the frustration level increases with the duration of the simulation. In terms of the team interaction index, which is based on the mean of the team survey results as well as the external observations, the high performers have the highest self-assessment at 4,6119 in comparison to the medium and low performer, scoring at 4,0688 and 4,1678. These results indicate a high level of cohesion within the high performer category. This tendency is also reflected in the results of the external observation.

Considering the overall competence assessment there are only minor differences between the three groups. Even though the high performer accumulated the highest score at 3,7134 it becomes apparent, that the medium and low performer considered themselves only slightly weaker, low performer considering themselves at 3,6872 even higher than medium performer with 3,4286. Similar tendencies can be observed in the analysis of the individual facet values. The low performer consistently considered themselves higher than the medium performer and regarding the facets of cooperation, coping with complexity as well as self-reflection even higher compared to the high performer. This indicates that their individual competency assessment may either be distorted or that the individual competencies may not have a predicting effect on team performance. Only the facets of action implementation and creative problem solving could have an impact on the simulation outcome, as the high performer considered themselves as the strongest regarding these facets scoring at 3,9230 and 3,9179. At the present state of observation, these results lead to the assumption that individual competencies are not necessarily the only predictors of performance. Thus, resulting in the question if there are certain characteristics of team teams themselves that influence a team's performance.

Considering the assumed moderators, it can be noted that the age range within the medium and low performer group is quite similar, showing a range of eleven and twelve years, leading to more homogeneous structures. Within the high performer group, the age range spreads to thirty years, which constitutes a considerably higher age heterogeneity.

In terms of gender diversity, it becomes apparent that the low performer are quite homogeneous with 85% female participants and 15% male participants. This could be an indicator for the lower performance, since the medium and high performer teams tend to be more heterogeneous when it comes to gender diversity, both being close to a 60/40 distribution. In terms of the study programme diversity, all teams show a certain level of heterogeneity, with the high and medium performer including higher rates of business-related students (64,1% and 66,7%) and the low performer including a higher rate of part-time students (50%).

Regarding the member familiarity it is noticeable that the high performer were most familiar with each other. Here, 59% of the participants stated that they knew all their team members. The familiarity level of the medium performer lies at 33,3% and of the low performer at 25%. In comparison, the familiarity of the high performer is noticeably higher. This tendency also applies to the moderator variable of the relationship between the team members. Here, 23,1% of the high performer considered their team members as friends whereas only 3,7% of the medium and 15% of the low performer could say the same about the relationship to their team members.

As far as self-efficacy is concerned it shows that even though the high performer rated themselves highest, the deviation from the low performer is rather small (0,0997). Regarding the collective efficacy, the high performers rate themselves considerably higher at 4,1949 than the medium (3,9037) and low performer (4,04), which could also be a consequence of the higher familiarity level within the high performer group.

At the current point of observation, it has to be noted that there is a possible distortion, namely the prior existing escape game experience of the teams. The data indicates, that with growing escape game experience the teams performed better. This could be attributed to the teams being more familiar with the way of thinking and logic necessary to solve escape games, which is usually rather similar. Therefore, it cannot be ruled out that the prior escape game experience has an impact on the team performance at the current state of the simulation. In a more optimistic way of data interpretation one can conclude that prior experiences with a challenging work setting impacts performance in a positive manner. This would be an argument for training on the (demanding) job.

In summary it shows, that at the current point of evaluation no clear tendencies regarding performance influencing competency facets on the individual level can be drawn. However, it will be interesting to further monitor whether the two competence facets action implementation and creative problem solving remain consistently higher when it comes to high team performance. It should be noted, that the positive influence of these facets may also be due to the simulation design, since these cognitive aspects are more relevant in order to be able to solve escape games in general. However, the analysis of the current set of observations indicates that team characteristics themselves in terms of familiarity of team members, heterogeneity regarding the age range as well as gender composition seem to have a positive impact on the performance of teams. Thus, team staffing seems to be more important than individual competence profiles.

The high performer showed a high level of heterogeneity within their group while simultaneously reaching the highest degree of cohesion, both regarding the team interaction quality and the familiarity level of the team members. These parameters appear to have a substantial influence on the team member's abilities to work effective within their team. Ultimately, these team characteristics could be the reason that teams that assessed themselves weaker regarding individual competencies nevertheless performed better than teams with a higher individual competence assessment, since they felt more secure within the group and thus resulting in a higher level of trust.

These tendencies are in line with the findings of Wilkens et al. (2017) stating that within front-end settings oriented towards collaborative work, the team level has a high impact on the actual performance. It is evident, that work within the collaborative ecosystem relies on heterogeneous work groups that have to be able to exchange and combine different perspectives (Mänz et al. 2013). These results also refer to findings from team research. Here, a higher level of team heterogeneity is positively attributed to team performance regarding complex tasks. Also, it is stated that higher levels of team diversity lead to higher team satisfaction and team outputs (Higgs et al. 2005). In order to benefit from different knowledge and skill sets that come with a high level of heterogeneity, it seems important that the teams furthermore reach a certain degree of cohesion. This result also confirms with findings from Paul et al. (2016) regarding the positive influence of cohesion on team performance of virtual teams. Contrary to back-end approaches such as learning factories that often focus on individual development goals for employees in manufacturing and production (Abele et al. 2010), for front-end settings there is a need to ensure development methods on the team level. Still, there is a need to transfer these findings into training practices in the context of industry 4.0. In terms of competency development for front-end work settings in the context of industry 4.0.

5. Outlook and conclusion

In recent years, various training scenarios have been examined and developed in the context of competence development for employees with regard to Industry 4.0 work contexts. These have mainly focused on the back-end field, directly addressing specific working processes and related output measurements. Besides back-end working processes, Industry 4.0 also impacts work processes in the front-end, for which comparatively few training approaches are known so far. Based on this, the present article addresses the performance measurement in the front-end on an overall systematic level. For this, a front-end training approach in form of a digital simulation laboratory with an accompanying measurement approach, focusing on the overall performance of teams, has been presented, integrating existing prior considerations from theory and practice.

The preliminary results show that the impact of individual competencies on the team performance was found to be less impactful as variables in terms of heterogeneity and team cohesion. These findings are in line with results derived out of existing team research. Although the present work presents preliminary results that need to be validated in future research, some implications can be drawn for practice for further competence training. For working within collaborative ecosystems, it seems appropriate to ensure a certain level of heterogeneity, especially regarding age and gender composition, while simultaneously promoting cohesion in terms of the relationship between team members resulting in a higher interaction quality as well as overall performance within the team. It seems appropriate to not solely focus on individual competence development, but also on the development of team structures and dynamics, as these ultimately ensure a certain level of performance quality. At this stage, it can therefore be stated that the team level has an effective and maybe even higher impact on performance than individual competencies tend to have.

In terms of limitations it hast to be noted that the current simulation is prone to distortions in form of prior escape game experience of the participants. For future research this should be considered. Also, it could be shown that individual competencies that are more focused towards cognitive skills in terms of combinative capabilities seem to have a positive impact on the team performance. This could be due to the design of the simulation as an escape game since these games are usually based on logical and combinative riddle designs. For future research the simulation setting therefore should be altered regarding the riddle design, for example by focussing more on creative problems that can only be solved in a collaborative manner. By doing so, the participants would not be able to rely on prior experiences in terms of logical and combinative patterns of action, gathered through former escape games.

The data evaluation was rather a first screening and qualitative evaluation. This means that findings have to be further validated in a test design. However, the gathered data and preliminary findings were most helpful to deduce hypothesis for a test design with respect to the influence of team characteristics and individual competencies on group performance.

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Workplace-integrated assistance systems conducive to learning designed for production

Tina Haase, Wilhelm Termath; Michael Dick, Dirk Berndt, Michael Schenk

1. Digital Assistive Technologies

Digital cognitive assistance systems already support the employee in many areas of work (Niehaus 2017). In the field of maintenance, the employee requests status data of complex technical systems, opens the latest maintenance documents for a malfunctioning component in the work situation and receives information about the machine and the colleague who conducted the last maintenance (Keller/Haase 2019).

In the commissioning department, the warehouse employees are guided using data glasses and pick-to-light.

In manual assembly, assistance systems are used to support employees in the assembly of increasingly diversified products. Step-by-step instructions on a display installed close to the workstation are currently the most common (Haase et al. 2020).

The very heterogeneous applications show the diversity of the required assistance contents as well as the different devices for their display. Various challenges accompany the use of digital assistance systems:

1) Ironies of Automation

Because of the increasing interconnection, automation, and digitization of machines and systems, the human task in the work system is changing more and more towards a monitoring and controlling function. The troubleshooting of minor malfunctions, from which employees could gain experience in the past, are hardly available today. Nevertheless, it is necessary and expected of the employee to react quickly, efficiently, and correctly to the failure situation. The dilemma of the "Ironies of automation" (Bainbridge 1983) makes clear that the support, on the one hand, leads to relief for the employee, but on the other hand, generates the need for new learning opportunities.

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2) Dequalification

Particularly in standardized processes and activities, the use of digital assistance systems is associated with the risk of employee dequalification. The technical system reliably provides necessary information for processing the next step and the employee executes it. It is often not necessary to understand why a work step must be conducted in a certain way or which alternative procedures would be possible. In this scenario, the employee has taken over the executing role in the cooperation between human and machine. There are operational scenarios in which this scenario has its justification, e.g. in the case of high employee turnover or the case of vacation replacements. To enable the employee to safely act in changing and complex work systems and to be able to generate new problem solutions from existing experiences, a holistic work design is required that prevents dequalification.

In this article, the authors consider assistive technologies for manual assembly processes and base the design of these systems on a fundamental understanding of the cooperation between humans and machines, which still assigns decisions and responsibility to humans. The assistance system is understood as a capability-enhancing system. It is designed in such a way that it enables learning in the process of work, expands the scope of action of the employees, adapts to their needs and the work situation, and contributes to quality assurance of the components to be assembled.

In this paper, the authors present a methodological approach for designing assistance systems conducive to learning. The theoretical framework is based on the activity system and the concept of expansive learning. From these, the authors develop the learning activity system. In section 3, the application and further development of this theoretical framework are presented based on an operational use case of mechatronics reprocessing. It includes a systematic approach to technology selection and design, which serves companies as a practical guide in the design of assistance systems.

In addition, dimensions of conduciveness to learning are developed and linked to the activity system approach. This integrated model provides requirements for the design of an assistance system that is conducive to learning. Finally, the authors show specific requirements and measures for a participatory design and implementation process.

2. From the activity system to the learning activity system

2.1. Activity system and expansive learning theory

The realization of the claim of a holistic, participatory work design, also in the design of the assistance system, requires a correspondingly broad theoretical framework to connect the individual learning of the working person with the organization's framework and its development dynamics.

The activity theory (Kölbl 2010) developed from works of the School of Cultural History (Leontjew 1979) distinguishes between activities, actions, and operations. In this understanding, activities in their representational character function as a connection between the individual and the organization or society. They represent material or ideal motive for the individual. The action, on the other hand, is a work action related to a specific objective, which is realized by executing individual operations.

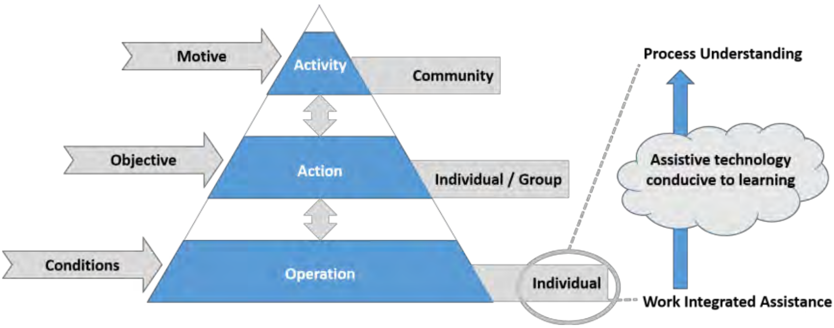


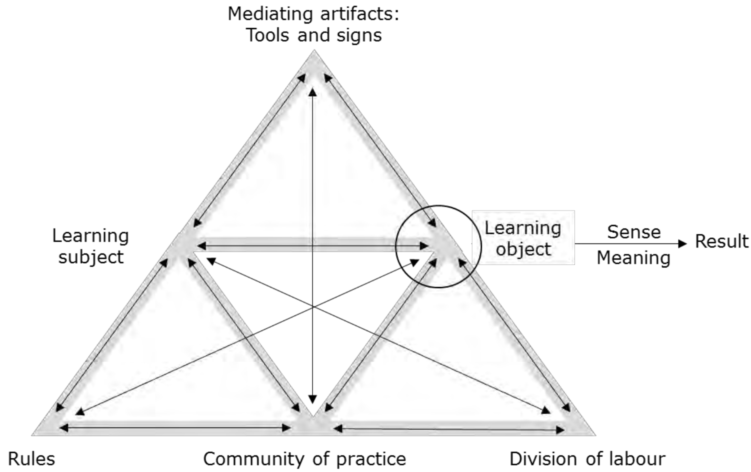
Figure 1: Activity system and assignment of the assistance system; following (Leontjew 1979)

The relevance of this distinction for the design of assistance systems is, first of all, to enable the working persons to relate to the object of their work as a meaningful and thus motivating element. In the automotive industry, for example, the screwing of a bolt into a certain base plate with a defined torque is an operation, the assembly of a mechatronic system is the overall objective, and the production of a car is the activity.

The visualization of Yrjö Engeström (Engeström 1987) illustrates the embedding of the subjects in the dimensions of the environment or organization as the basic structure of an activity system. (see figure 1).

The upper triangle of a subject, tool, and object stands for the individual who processes objects with the help of tools. The elements rules, community, and division of labor represent the organizational or social reference of an individual's actions. The set of these elements forms the activity system. For the activities of employees in an industrial company, the elements of the activity system can be described as follows:

The *Subject* is the acting person, e.g. as a worker on the shop floor, development engineer, or head of department.



The *Object* is the product in its entirety or parts, e.g. a car or a machine, but also the mission and the company's self-image.

Tools are on the one hand material tools such as machines, drills, or electrical diagrams, but on the other hand also methods, procedures, or expertise.

Figure 2: Structure of a human activity system
(Engeström 1987, cited in Engeström 2008)

Rules are both explicit regulations and procedural guidelines as well as implicit acceptance of a certain behavior or taboos.

Community refers to teams, shifts or departments.

The *division of labor* describes the cooperation of the different professions or departments in the value chain.

After empirical studies in institutions of medical care in the Helsinki area, among others, Engeström (2008) developed his research as an extension of the activity-theoretical basic model for understanding and integrating dimensions such as "... dialogue, multiperspective and networks..." (ibid. p. 64). The complexity of organizations can therefore only be grasped by analyzing several inter-active systems of activity, which include at least one common "collectively significant object" (ibid. p. 65).

The behavior of the individuals in this activity system or the work in a company that is understood as several interactive activity systems is therefore always characterized by contradictions between individual elements of the system or between several activity systems of the company. The perception of such contradictions -

e.g. the change of instructions or the restructuring of departments - requires from the individuals a corresponding adjustment of their behavior or way of working. In the understanding of the activity theory, these contradictions are important impulses for learning processes.

In the theoretical foundation of learning, Engeström refers to the work of Gregor Bateson (1983) with the distinction of three stages of learning. In the first stage the correct answering of questions or the "correction of errors in the selection within a set of alternatives" (ibid. p. 379), e.g. the correct handling of a tool, dominates. By learning II Bateson means an extension of learning I in the sense of a corrective change of the set of alternatives, possibly the idea for the use of another tool. Learning III finally means "... a corrective change in the system of sets of alternatives among which the choice is made" (ibid. p. 379).

Resulting contradictions, e.g. about the cost-effectiveness of a change in the use of tools or technology, can lead to fundamental changes in processes. Even if employees on the shop floor do not make these decisions themselves, it is important that they can experience their actions as a plausible and meaningful contribution to value creation.

2.2. Development of the learning activity system

The increasing integration of information technology into work systems motivated teams of researchers from the universities of Magdeburg, Bremen, and Karlsruhe to submit a research proposal in 2005 to explore the potential of virtual reality technologies for supporting individual and organizational learning in the work process (OLIVA 2007). In the first research period, individual learning processes were supposed to be supported by virtual learning media, in the second period this was extended to include cooperative and organizational learning. For the third phase, the vision of a "learning space virtual working world" was developed, in which individuals work and learn in distributed work systems in different domains and at various locations.

Engeström's activity system provided an analytical framework for conceptualizing both individual learning processes in the upper triad and their organizational embedding through the inclusion of the entire activity system (see above).

On this basis, Michael Dick developed the construct of the "learning activity system[s] as a unity of interrelated elements of work activity" (Dick 2007).

These perspectives provide the scientific frame of reference for designing an assistance system that is conducive to learning.

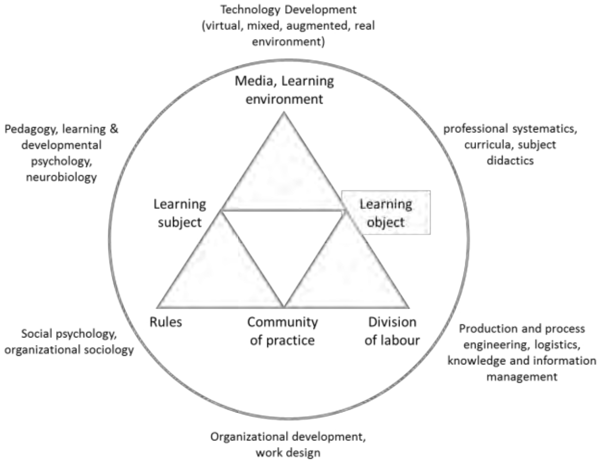


Figure 3: The learning activity system and the main scientific perspectives; following (Dick 2007)

3. Derivations for the design and implementation process

From the considerations of the activity system, expansive learning, and the derivation of the learning activity system, practical derivations for the design and implementation process of assistive technology systems conducive to learning that are integrated into the workplace are developed in the following. The first important influencing factors, which determine the later technology selection and design, are determined. For this purpose, different methods of work and requirements analysis are used. Then, concrete dimensions of conduciveness to learning are introduced and linked to the concept of the activity system. Sustainable use and acceptance of the developed solution are supported by a participative implementation and design process. In conclusion, important findings of this process from practical implementation are presented.

3.1. Parameters that influence the effectiveness of the assistance system

In the further development of the often technology-centered development processes, the effective use of assistance systems requires the consideration of multiple influencing factors.

The *employee* as a direct user of the system should be considered in his individuality to meet individual requirements and needs. These are, for example, the age, the level of competence and experience in performing the activity, as well as the motivation to learn, which can be derived from the personal motive (see figure 4).

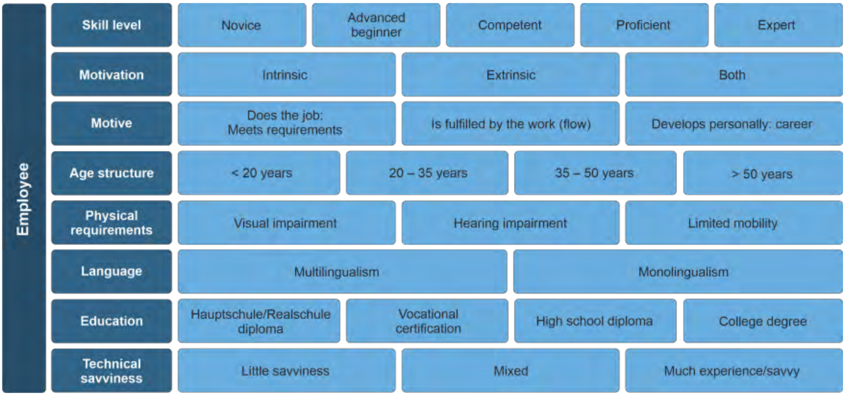


Figure 4: Employee dimension

The *learning object* includes the activity, its embedding in the overall process, and knowledge about the object that is the subject of the activity. Here, relevant content should be identified that supports the identification of the learner with the product and the activity and thus contributes to the creation of meaning.

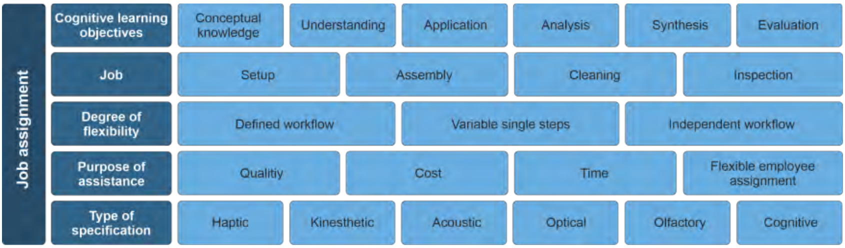


Figure 5: Job assignment dimension

In addition, the learner's involvement in the *community of practice* should be analyzed to obtain indications of the members of the community of practice and existing possibilities of experience exchange, which must be taken into account when designing exchange processes with the help of the assistance system. This is closely related to the rules, norms, and values that are practiced in the organization and can be seen, for example, in the learning and error culture. Information on these parameters usually requires a well-developed trust relationship and can be mainly collected in informal processes, e.g. through participant observation.

The conditions at the workplace have a significant influence on the selection and design of the technology. Therefore, the identification of factors such as volume, brightness, spatial conditions, and existing IT systems is an essential part of the analysis process (see figure 6).

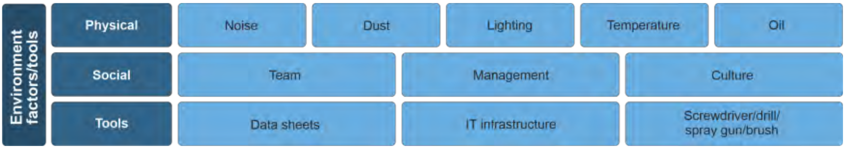


Figure 6: Environmental factors dimension

3.2. Conducive to learning and work integrated assistance system

A large number of digital assistance systems developed in recent years to support assembly processes have focused primarily on providing the correct sequence of operations. Examples include pick-to-light systems or desktop displays in the automotive industry. This type of guided and alternative-free specification of correct partial operations without background information and the possibility of exploration tends to restrict learning processes and to dequalify employees (cf. Frieling et al. 2006).

Further development of these systems into assistance systems that promote learning and contribute to development processes among employees requires concrete design criteria (Haase et. al. 2020). They follow the criteria of a working design that is conducive to learning and competence (cf. Franke/ Kleinschmitt 1987; Dehnbostel 1994; Franke 1999) and supplement these with the dimension of system-immanent motivational incentives.

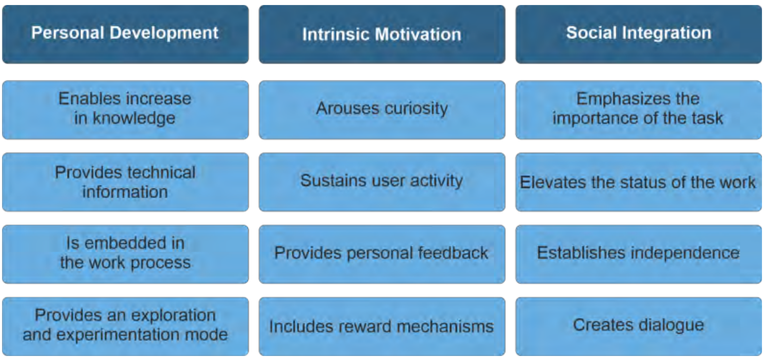


Figure 7: Conduciveness to learning dimensions and derived criteria, following (Fredrich et al. 2021)

The specified criteria (see Fig. 7) are intended to go beyond mere adaptation to a predefined sequence of assembly steps and cover a subjective educational potential. This can consist, for example, of deepening and broadening existing knowledge and thus linking individual goals, or of placing oneself in a collegial context and participating in the further development of work processes. Making one's contribution to the overall performance visible creates meaning and identity (Wehner et. al. 1996). The assistance system can become the symbol and artifact of a "community of practice" (Wenger 1998). Mechanisms that arouse curiosity and sustain engagement with the object of learning can support these processes.

3.3. Integration of activity system and design conducive to learning

Concerning the learning activity system, these criteria of conduciveness to learning can be related in summary to the three levels of learning (see Section 2.1).

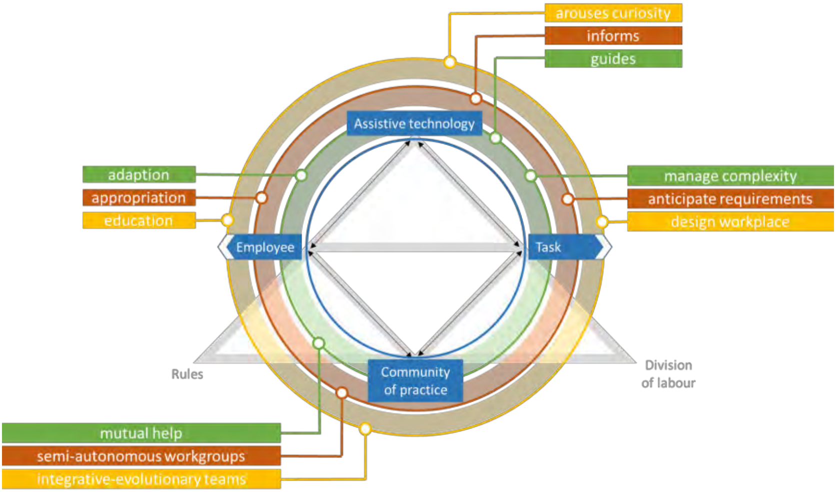


Figure 8: Conduciveness to learning in the activity system

At the Learning I level (operation; inner circle), the assistance system supports the execution of an operation and thus has primarily an instructional function.

A system that enables learning II (action; middle circle) contains further assistance content that supports understanding and thus enables transfer to similar actions. It is oriented to the objective.

Learning III (activity; outer circle) does not take place in the assembly directly by the employees themselves, but more on the management level. The motives of the group and the associated operational goals should also be known to the assembly employees to be able to relate their actions to these goals. In mechatronics preparation, for example, an explanatory video has been created that clarifies the contribution of mechatronics preparation as a contribution to the organization's sustainability strategy. It thus serves to motivate the employees and give them a sense of purpose.

3.4. Participatory implementation process

The effectiveness of an assistance system is significantly determined by the acceptance of the system by the employees. If it is achieved that the system becomes a self-evident "tool" of the employees, constant use and thus also an up-to-dateness of the contents can be enabled.

The creation of acceptance, combined with sustainable use and a shared vision of the effectiveness of the system, requires a negotiation process between professional, work design, and technological perspectives in the early phase of system design (see Fig. 9).

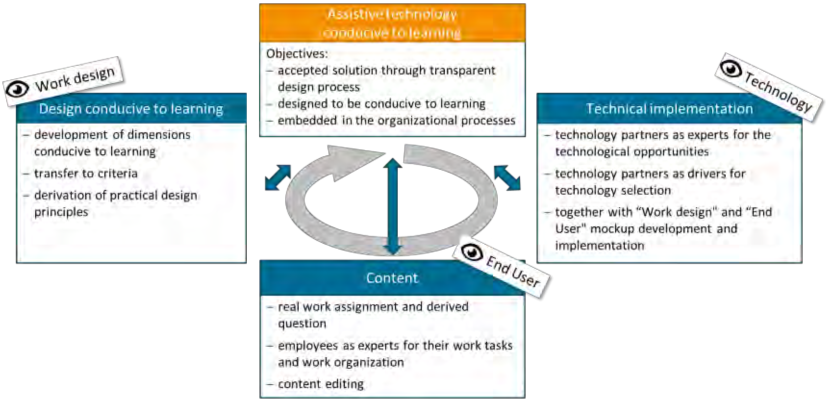


Figure 9: Interdisciplinary negotiation process

In this context, work design as the realization of a didactic concept focuses on the design that is conducive to learning and the embedding of the assistive technology solution in the work organization of the company. The resulting changes must be made visible at an early stage and their effects must be made tangible. The users stand for the validity of the assistance content and the relevance of the task supported by the system. The employees are the experts for their workplace, the organization with its rules, norms, and values and they are part of the community of practice. Designing a digital assistance system also requires a technological perspective and expertise. Technology experts know the technical scope of possibilities, can link the new solution to the existing IT infrastructure, and thus provide the impetus for technology selection. A solution that reflects all perspectives equally requires an awareness of these perspectives on the part of everyone involved and a willingness to make the design decisions in this area of tension together.

4. Application of the learning activity system in practice

In the BMBF-funded research project LeARn4Assembly (FKZ: 01PV18007A), assistance systems conducive to learning are designed and implemented. The application of the learning activity system and the process of designing and introducing a new assistance system are described about a scenario of mechatronics assembly at Audi.

Figure 10 uses the example to show four selected references of the learning activity system, which illustrate the interaction of the elements in the system when designing, introducing, and accepting assistance systems:

A) Assistive technology to transfer knowledge about the mechatronics

Assistive technologies conducive to learning have the potential to provide knowledge about the product to be manufactured beyond support in operating, and thus to integrate the actions of the employee into an overall process. This can include, for example, how the mechatronics works and how it is installed and operates in the car as the higher-level overall product. In this way, the assistance system contributes to making sense of one's activity and to supporting the identification of the employee with the activity, the product, and the overriding motive of the organization (Learning III).

B) Assistive technology for the documentation and provision of experience-based knowledge, e.g. tips and tricks for the handling of the mechatronics

In addition to the instructional provision of assistance content for performing the activity, employees appropriate expert knowledge in their activities, which enables them to act confidently in special situations. Employees usually do not document this experiential knowledge, but exchange it informally in conversations. If such an exchange does not take place, for example, because the opportunity does not present itself or because the person providing the knowledge has reservations about passing it on, the potential of the individual is not passed on to the organization.

The assistance solution tested at Audi will therefore also enable the documentation and use of experiential knowledge in the work process (Haase et al. 2013) (Gerhardt et al. 2020) and thus support an exchange between the employee and colleagues as a community of practice.

C) Assistive technology for the transfer of upstream and downstream processes, e.g. contribution of mechatronic reprocessing to the sustainability of the company

The effects and consequences of one's actions often remain hidden from the employee. For example, the employee is instructed to carry out a process in a certain way, but the reasons are often not communicated. An assistance system that makes these interrelationships transparent to the employee can help to increase the employee's quality awareness because the consequences of a different procedure for the subsequent processes are pointed out. The employees in mechatronics processing, for example, play a major role in the organization's sustainability strategy. In the project, an explanatory video was created that makes this connection transparent and comprehensible for the employees.

D) *Assistive technology to promote a learning and failure culture, e.g. by reflecting and updating assistant content*

The design of assistance systems is also an indication of the learning and error culture that is practiced in the organization. A system that understands itself as an exchange platform between employees, by going beyond formal rules, for example, by documenting their experiences, tips, and tricks there and sharing them with the community of practice, different ways of acting are revealed and thus provide an incentive for exchange, improvement, and learning in the organization. The solution developed in the project at Audi will promote this culture by enabling the technical solution to comment on and evaluate the documented knowledge modules. This is intended to raise awareness of the need for continuous reflection on knowledge and to allow employees to actively participate in shaping it.

5. Summary and outlook

Digital assistance systems will increasingly be used to support manual assembly processes. In addition to providing direct support in performing the activity, assistance systems will also make an important contribution to human-centered work in the future. Current research shows that content conducive to learning can contribute to the enhancement of one's activity and thus to a strengthening of employee identification with the company, the product, and the activity. Possible contents, such as the function of the component to be assembled, the costs incurred or one's contribution to the sustainability of the company, enable the employee to classify his activity in the company process. The activity system and the learning activity system derived from it provide a suitable explanatory framework for this.

In addition, the danger of de-qualification can be counteracted and monotonous work sequences can be broken.

This requires a design process that starts from a relevant operational question, follows a systematic process of technology selection, and design and involves the employees in this process.

One target category that has not been addressed in this article and that will gain importance in the future is the adaptability of companies. Assistance systems can be an important building block for strengthening the adaptability of companies, since they rapidly reduce learning times, among other things. The activity system provides the analytical framework and makes clear that contradictions that repeatedly occur in company practice can be understood as opportunities for change and innovation, see Learning III.

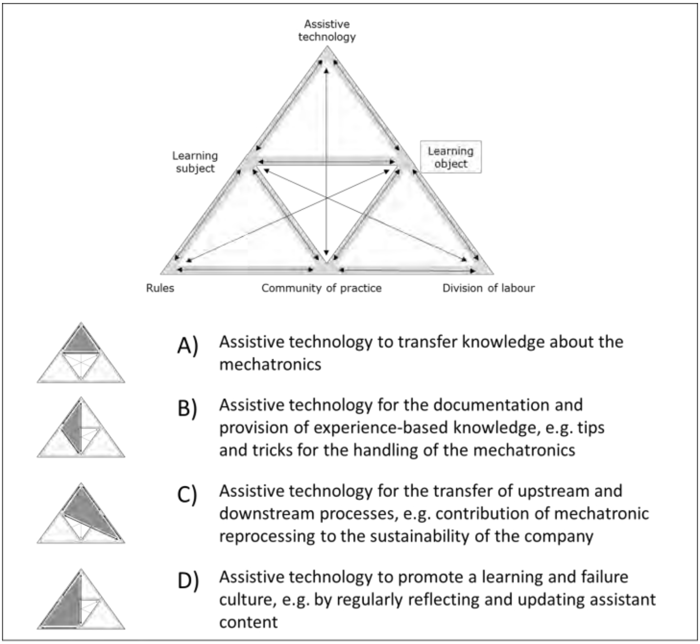


Figure 10: Application of the learning activity system for the design of conducive to learning assistance systems

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A Modular Federated Learning Architecture for Integration of AI-enhanced Assistance in Industrial Maintenance

A novel architecture for enhancing industrial maintenance management systems in the automotive and semiconductor industry.

Linus Kohl, Fazel Ansari, Wilfried Sihn

1. Introduction

Artificial Intelligence (AI) plays an increasingly important role for implementation and failure-free operation of Cyber-Physical Production Systems (CPPS). Recent market studies reveal the considerable attention and increasing rate of investment for AI-enhanced maintenance as one of the major use-case of AI in Industry 4.0 (Brügge et al. 2021). AI systems enable the improvement of various Key Performance Indicators (KPI), ultimately leading to a reduction in costs and optimizing plant management in smart factories (Fink et al. 2021; Passath et al. 2021). However, their development, implementation and deployment require a high level of expert knowledge and cost-intensive (computational) resources as well as reliable infrastructure (Fischbach et al. 2020). In addition to expert and prior knowledge, the available data is also an essential criterion for successful implementation of an AI system. At the same time, manufacturing enterprises in diverse sectors have very high expectations from any kind of AI solution comparing to conventional solutions. A study by Arinez et al. (2020) shows that research on AI in industrial context and specifically in manufacturing is mainly limited to laboratory environments. This is due to the high effort required to overcome existing (non-)technical barriers for implementation and integration of AI systems in the manufacturing systems and processes. In the course of digital transformation, it becomes more and more imperative that manufacturing enterprises consider the disruptive nature of AI technologies while understanding the demands on organizational change and competence building to realize the full potential of AI (Schumacher/Sihn 2020).

The study conducted by Henke et al. (2016) concludes that manufacturing enterprise use only 20-30% of their data and therefore leave an enormous, untapped potential. In addition, according to Gandomi and Haider (2015), about 80-95% of all business-relevant data is available in unstructured form, i.e., text. From these

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facts, it can be deduced that it is necessary to go beyond the conventional approach, which states that data in production only comes from machines via mounted physical sensors. The variety of data structures, i.e. multi-structured data sources, offers a new possibility to introduce new kinds of virtual sensors. Those virtual sensors can provide an even better data basis for subsequent decisions by analyzing expert knowledge hidden in texts. A notable example is maintenance, where related preventive and troubleshooting processes mostly provide written machine inspection, failure and maintenance reports created by maintenance technicians. These reports reflect human experiential knowledge about conditions, faults, causes, and solutions recorded in unstructured form. The use of Text Mining (TM) realizes the untapped value of existing unstructured or semi-structured textual data. TM is defined as applying AI algorithms and methods to text to find valuable patterns (Gao et al. 2020; Hotho et al. 2005). Therefore, an AI-enhanced system is needed to extract the full information available in the industrial environment to derive the required KPIs for optimizing manufacturing and maintenance processes.

The goal of this paper is to introduce an architecture for a modular cognitive maintenance system. The main objective is to design a system, which utilizes the unexploited potential from combining structured and unstructured data, by using AI technologies. The proposed AI-enhanced approach should improve various operational KPIs in particular availability and OEE, which will ultimately lead to a reduction in costs in industrial maintenance. The main research question of this paper is therefore, "How should the architecture of a modular cognitive maintenance system be designed to ensure industrial applicability in the context of maintenance?"

The rest of the paper is structured as follows: Section 2 describes the functional capabilities for AI-enhanced Assistance Systems. Section 3 presents a cognitive maintenance system, named ARCHIE. Section 4 explains its application using two use-cases from the automotive and semiconductor industry, respectively. Finally, Section 5 discusses the results in the use case and highlights avenues for future research.

2. Functional capabilities for AI-enhanced Assistance Systems

Functions typically associated with human intelligence include reasoning, learning, and self-improvement. AI as a sub-discipline of computer science aims to develop systems able to perform tasks that typically require human intelligence. AI itself is defined by Russell et al. (2010) as "the designing and building of intelligent agents that receive percepts from the environment and take actions that affect that environment". In Industrial AI, the focus is on developing, integrating, validating, and deploying AI systems in industrial processes, services, and systems (Peres et al. 2020). In this context, five dimensions in industrial AI were identified by Peres et al. (2020), namely i) infrastructure, ii) data, iii) algorithms, iv) decision-making and v) objectives.

In order to employ AI technologies in industrial context effectively, it should be ensured that the used data, the structure of the data and the data quality, as well as the correct interpretation of the discovered knowledge, is guaranteed. Especially in manufacturing, data is usually combined from different sources (e.g. machines, processes), which in turn are recorded in various data formats (e.g. structured and unstructured) (Ansari 2020). This problem of multiple data formats is aggravated by the fact that the recorded data is often very noisy (e.g. incomplete, inconsistent, or even faulty). This requires focusing on preparing and selecting the data, which consumes considerable time and resources in real world use cases and industrial projects. Therefore, only with appropriate pre-processing steps can the developed AI algorithm achieve optimal results with the selected data (Ansari et al. 2021).

In the era of Industry 4.0, the importance of lot-size one increases, which places high demands on workers' cognitive abilities in production and maintenance (Ansari et al. 2018). In particular, flexibility, adaptability and problem-solving abilities are required (Zdravković et al. 2021). The realization of comparable cognitive skills in an AI-based agent system holds immense potential for developing industrial assistance systems. Those systems provide intelligent functions that can, inter alia, facilitate solving common problems of make-to-order production such as high manufacturing costs, long lead times and varying quality levels (Zaeh et al. 2009). These problems can be overcome while at the same time assisting workers in their work processes by using cognitive systems (Li et al. 2019).

In manufacturing and maintenance systems, cognitive capabilities refer to the ability for machines and processes to be equipped with cognitive skills and cognitive controls that enable them to assess their scope of action and act autonomously (Park et al. 2009). A cognitive control system consists of three general functions (Park et al. 2009), namely i) capturing information from the environment, ii) draw conclusions from the information acquired based on existing knowledge, and iii) act to implement a reasoned change in the environment. These three functionalities allow technical systems to "know what they are doing" (Zäh et al. 2007). Production and maintenance planning in such a system should be autonomous and proactive (Hu et al. 2019; Iarovyi et al. 2015). Planning should be able to schedule multiple production and maintenance activities simultaneously, online, reactively, and opportunistically. Therefore, a corresponding feedback loop of current state information to the respective controls should be realized (Zhao/Xu 2010). Based on Zhao and Xu (2010), the following five extended functionalities should be fulfilled by a human-centered cognitive assistance system in production and maintenance planning:

i) Data acquisition with physical and virtual sensors.

ii) Automatic decision making

iii) Self-adaptation to sudden and unforeseen changes.

iv) Complete understanding of the production and maintenance process

v) Human-centered information support

These functional capabilities are implemented jointly by software, hardware, artificial (e.g. machine), human, and organizational agents. Those agents are then mapped into a cooperative multi-agent system (Jones et al. 2018).

Considering the state of the art in applying cognitive and AI-enhanced systems in maintenance, it can be summarized that despite the availability of data from various information channels, they are still hardly used in combination. Therefore, subsequent use of the extracted information to build a learning system that utilizes different machine data and human experiential knowledge to optimize maintenance processes is also missing. The existing body of knowledge analysis clearly reveal that a corresponding application is lacking in both research and industrial context. Some of these concepts have been implemented. However, the holistic implementation with the human being in the loop is still missing in the current research and industrial landscape.

3. ARCHIE: Architecture for a Cognitive Maintenance System

The objective of human-centered cognitive systems is to automate manufacturing processes further and assist workers in their cognitive tasks (Fischbach et al. 2020). This can be achieved by using the untapped potential of combining unstructured and structured data in order to extract hidden knowledge. The designed Architecture for a Cognitive Maintenance System (ARCHIE) aims at realizing the aforementioned AI-enhanced approach for a human-centered assistance system. ARCHIE incorporates physical and virtual sensors that capture machine states, parameters, human knowledge, and skills to optimize relevant KPIs. This includes a reduction in documentation time, Mean Time Between Failures (MTBF) and Mean Failure Detection Time (MFDT), as well as an increase in uptime, leading ultimately to an improved Overall Equipment Efficiency (OEE). The design principle of ARCHIE is based on the consideration of data from multiple channels. Data is collected by physical sensors (e.g. machine data, image data) and virtual sensors (e.g. audio, text). This data collection can provide a comprehensive picture of the environment and thus provide the cognitive maintenance system with an optimal set of necessary information. This data includes the objective machine and process information provided by connected systems and the subjective assessments of machine operators and maintenance staff, based on their respective skill levels.

The collected holistic data landscape enables the targeted deployment of maintenance measures, at the right moment, on the right machines, with the most suitable maintenance technicians. This directly improves KPI's such as availability and performance. Indirectly, the human-centered support of maintenance activities can improve the quality of these activities and therefore influence the KPI quality. Those improvements result in a general increase in the OEE.

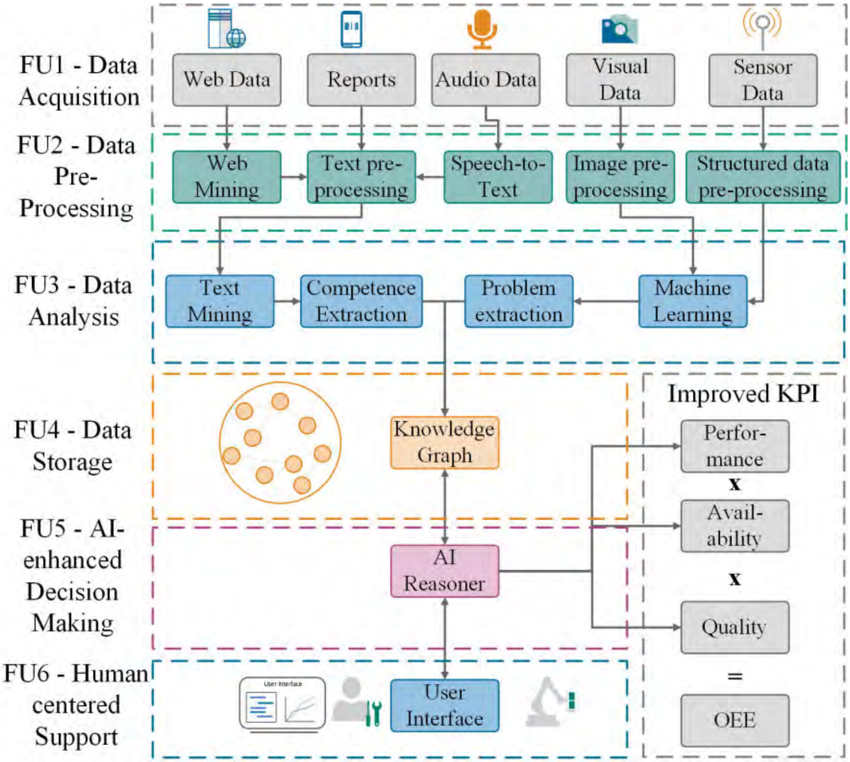

Figure 1: Design principle and functionality of an Architecture for a Cognitive Maintenance System (ARCHIE)

As depicted in Figure 1, ARCHIE is composed of 6 major functional units (FUx).

FU1 - Data Acquisition: The architecture of ARCHIE provides flexible interfaces to meet the idea of multi-channel data acquisition. Data sources can be captured as a.) structured data from sensors, and b.) unstructured data (e.g., text, image, or audio data which is converted to text).

FU2 - Data Pre-processing: Depending on the data source, the pre-processing modules in ARCHIE prepare the content for the subsequent analysis module. In the case of structured data such as sensor data, these are normalized for the downstream Machine Learning (ML) models or one-hot encoded in the case of categorical data. Audio data, such as speech recordings, are transformed into textual data using speech-to-text algorithms. Textual data can also be extracted from corporate knowledge resources via web scraping. The textual data is tokenized, stop words are removed, followed by lemmatization and part-of-speech tagging to identify semantic relations in the sentence structure and to prepare the text for downstream analysis. In particular, use-cases, it is also necessary to create use-case-specific dictionaries in order to deal with technical vocabulary or enterprise-specific words.

FU3 - Data Analysis: The chosen data analysis unit depends on the data source and data type, which results in the use of different algorithms. In the case of structured data, ML methods are used to perform analysis such as downtime prediction (Ansari et al. 2021) and detection of critical machine failures (Passath et al. 2021) or anomalies, depending on the requirements. For unstructured data, TM models are used to extract e.g. maintenance activities, competencies, or keywords for later semantic annotation of the text. Image data can also be analyzed with ML models to provide further information on potential defects or quality issues.

FU4 - Data Storage: The data storage in ARCHIE takes place within a so-called Knowledge Graph (KG). The KG allows entities from the real world and their relationships to each other to be mapped in a graph structure (Paulheim 2016). Examples for those real-world entities include maintenance technicians, machine operators, fault messages, sensor values of machines, internal maintenance documents, and maintenance reports. However, abstract entities like competence, knowledge, and job description have connections to physical objects and can also be modeled in such a structure (Ansari et al. 2020). In ARCHIE, these entities represent so-called classes with different parameters such as author, sensor value, activity, competence level, which are related to each other. The graph structure of the KG enables a subsequent determination of hidden relations and optimal recommendations for action derived from them. Those recommendations range from selecting the most suitable person for solving a given machine malfunction, recommending maintenance measures for a given problem, or evaluating required competencies for specific machine types.

FU5 - AI-enhanced Decision Making: The AI-enhanced decision-making uses the KG provided in ARCHIE and utilizes it to suggest the most suitable action with the help of statistical and similarity-based learning algorithms. Similarity-based learning algorithms are used, among other approaches, to present potential causes of machine failure or maintenance measures for a given failure. Statistical learning algorithms can be used to extract and evaluate tasks performed or competencies required from maintenance reports. The aggregation of these results from the similarity-based and statistical learning algorithms can then be used to select the most suitable person for an existing machine malfunction and support this person according to his competence level in solving the problem. These algorithms can be implemented with Federated Learning (FL). The use of FL prevents the exchange of sensitive data with the central server and allows the assistance system to be used at consumer devices even without a network connection (Bonawitz et al. 2019).

FU6 - Human-centered Support: The results of the AI-enhanced decision-making are used to provide individualized recommendations and documentation support for machine operators and maintenance technicians. This assistance is additionally supported by a human-centered design that puts the user's needs in the respective maintenance workflow in the middle of the design focus. ARCHIE is based on supporting people in their work through intuitive user design so that no additional time is required due to the usage of ARCHIE by providing the right information at the right time in a suitable way for the task at hand. The operative use also requires a high level of acceptance among the users of ARCHIE. This support is achieved by developing the user interface in very close cooperation with the users and decision-makers in the respective use-cases. However, ARCHIE also provides generic building blocks such as finding similar entries, word suggestions, maintenance task suggestions, assessment of required competencies, and predictions of KPIs. Through this combination of customization to user and use-case, as well as generic, proven building blocks, ARCHIE can demonstrate its added value in maintenance through reduced documentation time, MFDT, faster problem solving and increased documentation quality.

The FUs can be used individually for each use-case. In combination, however, they exploit the full possibilities of ARCHIE. ARCHIE can also be implemented as part of a comprehensive maintenance model such as PRIMA (Ansari et al. 2019). Therefore, the design principle shown in Figure 1 represents a modular structure that allows a partial validation of ARCHIE.

Additionally, ARCHIE addresses the five identified and extended challenges in implementing an AI system in an industrial environment (Lee et al. 2018; Fischbach et al. 2020).

1) **Generalizability:** The developed architecture does not focus on one industry but rather represents a generic architecture that can be adapted to the respective industry, enterprise, and application through minor adjustments. Therefore, the AI algorithms are initially trained on data from scientific studies and European specifications, and only enterprise-specific adjustments are required for fine-tuning. The use of FL allows ARCHIE to be deployed in areas with high data sensitivity requirements or insufficient network coverage.

2) **Scalability:** ARCHIE aims to be easily scalable from a single component or one-machine use-case to the entire machine group or factory.

3) **Customizability:** To provide ideal support, ARCHIE can be individualized using employee competencies. These enable the provision of information in line with the level of training and qualification or the specific job role.

4) **Reliability:** In modern industrial manufacturing environments, the reliability of AI systems is of paramount importance, as failures can result in high costs. ARCHIE, therefore deliberately relies on a robust algorithmic basis that can handle outliers, erroneous and missing data.

5) **User acceptance:** No AI solution, no matter how sophisticated, will succeed in the industrial environment if the users do not accept it. ARCHIE focuses on human-centered design with an emphasis on intuitive use and gender-neutral design.

4. Proof of Concept Application of ARCHIE in Industrial Use-Cases

4.1. Automotive Industry

In the use-case of maintenance in the automotive industry, an AI-enhanced methodology for a digital shift book has been developed. The goal of the Proof of Concept (PoC) application was to increase the OEE by providing accurate downtime prediction and assistance in documentation (Ansari et al. 2021). In the use-case the FU1-3 and FU6 have been implemented and validated. The automotive manufacturer's data spans three years and includes Rough Problem Level, Fine Problem Level, Defective part, Problem and, Downtime.

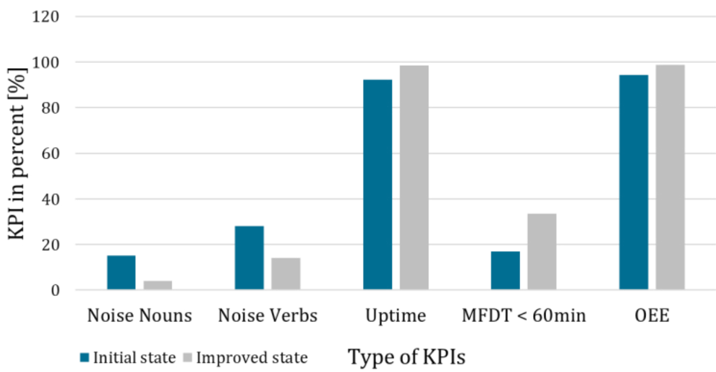

Figure 2: Improvements through the AI-enhanced methodology by Ansari et al. (2021)

The data acquisition unit was implemented using structured and unstructured data from maintenance reports (Ansari et al. 2021). In the pre-processing unit, as described in detail in Ansari et al. (2021), structured data was normalized, and outliers were removed. In the case of the unstructured data, among other things, stop words were removed and lemmatization was performed to extract nouns and verbs. In the data analysis unit, the unstructured text data was vectorized, and the structured data was used as target values for training a ML model. Based on the error description of the machine operator, the developed model allows predicting the expected downtime of the machine. The human-centered support unit was developed as a web application as an assistance system for the maintenance technician during the diagnosis of the causes of the machine failure and the subsequent problem-solving. As shown in Figure 2, the AI-enhanced digital shift book improved the MFDT below 60 min by 97.3%, and ultimately the OEE by 5.3% percent.

4.2. Semiconductor Industry

In the use-case of maintenance in the semiconductor industry, an assistance system has been developed, which uses the data of a digital shift book as a data basis for predicting the necessary competencies for a given maintenance task (Kohl et al. 2021). In the use-case the FU1-2 and FU4-6 have been implemented and validated. The data acquisition unit uses unstructured text data from maintenance reports, including the machine, the machine group, the error description, the cause of the error and the maintenance task carried out. For the pre-processing unit, as described in Kohl et al. (2021), a use-case-specific dictionary was created in addition to stop word removal and lemmatization. The dictionary contains synonyms as well as enterprise-specific expressions. This enabled the TM algorithm to extract the tasks listed in the respective maintenance reports. The approach reduced unique nouns to a tenth and verbs to a fourth of the starting value.

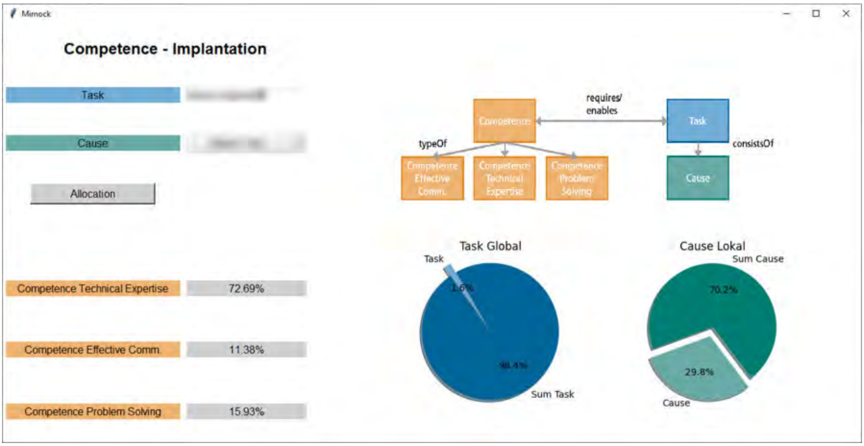

Figure 3: User interface of the assistance system for quantifying the competence distribution based on a task and its assigned cause

Additionally, a competence taxonomy, based on Ansari et al. (2020), for the KG in the data storage unit and a statistical learning algorithm as an AI-enhanced decision-making unit was developed. With those adopted FUs of ARCHIE, the extraction of required competencies for a given maintenance task was achieved. In a further step, the necessary competencies for the respective activity could be broken down to internal competence levels and job descriptions derived from them, with the help of the algorithm and companies' internal job descriptions. For this purpose, as shown in Figure 3, the human-centered support unit, a user interface, was designed. The developed user interface allows for simple querying of the competence distribution based on a task and its assigned cause. This functionality also allows a better and automated allocation of maintenance technicians based on the current task and their corresponding profile. The statistical learning algorithm additionally makes it possible to analyze the evolution of the tasks over time. From these analyses, maintenance managers can derive recommendations for reskilling and upskilling employees and optimizing shift plans according to predicted needs.

5. Discussion and Outlook

This paper presents a transferable and scalable architecture for a cognitive maintenance system of a human-centered assistance system that enables holistic sensing of the environment by using physical and virtual sensors. Therefore, it fills the identified gap in the literature of production and maintenance management and related industrial applications. By focusing on generalizability, extensibility, adaptability, reliability and user acceptance, ARCHIE addresses common challenges in the application of AI systems in the industrial environment. In the presented use-cases, the generalizability, scalability, customizability, reliability and user acceptance were evaluated. The limitations of ARCHIE can be derived from the design of the FUs. As a data-driven approach, the FU1-2 require multiple (digital) data sources. Adopting the FU3-6 for the respective use-case also requires business understanding in particular with regard to the requirements for employing an AI-based system in the industrial IT landscape. It is also worth noting that the deployment phase will confront challenges regarding system integration, especially the interoperability of FU with the corresponding IT systems. The modularly designed six FUs form the basis for an adaptive, cognitive maintenance system that can assist humans during the maintenance process. In particular, the KPIs performance, availability and quality are improved, which leads to an increased OEE. This could be demonstrated by partial implementations of ARCHIE in two industrial use-cases, namely in the automotive and semiconductor industry. The presented architecture and the results of the use-cases show how the implementation of a cognitive maintenance system using AI can improve industrial maintenance by proof of concept evaluation in two use-case.

Important future research areas are the customizability of the cognitive maintenance system for user-specific support, the linking and use of information from information systems in manufacturing and especially maintenance (e.g. Enterprise Resource Planning, Manufacturing Executions System), as well as the automated determination of the criticality of plants and the derivation of RAMS (Reliability, Availability, Maintainability, Safety). Based on the current FUs of ARCHIE and the presented future research directions, further functionalities and new compositions of FUs should be implemented and evaluated in industrial context.

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Neuro-adaptive tutoring systems

Neurophysiological-based recognition of affective-emotional and cognitive states of learners for intelligent neuro-adaptive tutoring systems

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1. Introduction

In the last decade, a growing number of studies have focused on decoding activation patterns from neurophysiological measures to identify current cognitive or affective-emotional states (e.g., Appriou et al., 2020; Fairclough, 2009; Parasuraman & Rizzo, 2008; Picard, 2000). The detection and monitoring of learners' mental states by means of a brain-computer interface (BCI) enables a continuous assessment of currently available cognitive resources, attention, and motivation. A BCI is a technical interface between the brain and a computer. In most cases, sensors on the surface of the head or skin are used to measure signals from the peripheral and central nervous system (e.g., the electroencephalography, EEG for recording brain activity). Machine learning techniques allow to process these signals and classify current mental states of learners. In a next step, the recognized states can be transmitted to a computer, for example, an intelligent tutoring system (e.g., Wolpaw et al., 2002; Vukelić et al., 2021).

In this paper, we provide an overview of research on neuro-adaptive systems and the recognition of affective-emotional and cognitive states. Current research findings are presented and explained within the illustrative application of a neuro-adaptive tutoring system. Chapters 2 and 3 present two validation studies on the continuous neuro-physiological based recognition of affective-emotional and cognitive states. The results of the studies and their implications are discussed in Chapters 4 and 5. Finally, an outlook on future research questions and methodologies is provided.

1.1. Neuro-adaptive systems and Brain-Computer Interfaces for recognizing the learners' states

A neuro-adaptive system is a system in which (1) neurophysiological signals are recorded in a closed human-technology loop, (2) mental user states are interpreted from these signals, and (3) system behaviour is adapted, accordingly. A neuro-adaptive closed-loop system has the great potential to adapt learning content,

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learning speed, and learning formats to the needs and abilities of the learners via an intelligent tutoring system. A major achievement in the field of neuro-adaptive systems has been the development of "passive" BCIs (e.g., Zander & Kothe, 2011). The main difference between passive BCIs and the more familiar "active" BCIs is that passive BCIs record implicit and spontaneous brain activity. In active BCIs, users voluntarily and mentally transmit specific commands to a computer application – they, thus, "actively" take control (for example, in physically severely impaired stroke or locked-in patients, e.g., Bensch et al., 2007; Brauchle et al., 2015; Carlson & Millan, 2013; Leeb et al., 2015). In contrast, passive BCIs do not require voluntary actuation. Hence, the person is not disturbed in his or her current task. For state detection, different measurement methods can be combined to create a hybrid BCI (e.g., an EEG with an electrocardiography (ECG) to collect cardiac activity, additionally). The use of multiple measurement methods has the advantage of a more robust and convergent estimation of the current mental states.

In addition to the system adaption towards the learner's needs and abilities, providing feedback to him or her on the current affective-emotional and cognitive states can promote self-regulation (Yu et al., 2018) and improve cognitive performance via neurofeedback (Dessy et al., 2018; Kosuru et al., 2019). Perceived successes during learning, lead to pleasant affective-emotional states, such as pleasure, promote perceived self-efficacy, and positively impact intrinsic motivation and, thus, performance in everyday and professional contexts (Shockley et al., 2012; Niklas & Dormann, 2005).

1.2. Cognitive load and affective-emotional states during learning

For the work context, concepts of lifelong learning (LLL) and employee training and reskilling are crucial for performance and maintaining competitiveness (World Economic Forum, 2019). Therefore, an optimal fit between learners and cognitive demands of the learning unit is desirable. Mental or cognitive (work)-load is defined as the ratio of available mental resources relative to the resources required to complete a task (Hart & Staveland, 1988). The more the available resources are required by the demands of a task, the higher the (perceived) cognitive load. Too high cognitive load, e.g., due to training units that are too difficult or demanding, is associated with occupational exhaustion, stress, fatigue, and, consequently, reduced performance (Bowling et al., 2015; Gevins & Smith, 2003; see also DIN EN ISO 26800 2011). Contrarily, too little stimulation and cognitive demand can lead to underload, loss of focus, and even reduced abilities (see Young & Stanton 2002; Young et al., 2015). In the case of an optimal fit between the task difficulty and the learner's abilities, a state described in positive psychology as flow can occur. This flow state is characterized by the fact that the performance of the task is perceived as rewarding and the person is absorbed in the activity (e.g., Nakamura & Csikszentmihalyi, 2009).

1.3. Physiological correlates of cognitive load and affective-emotional states

In order to use the neuro- and peripheral-physiological signals for decoding mental states, it is relevant to identify informative patterns and dynamics. Regarding the visceral or autonomic nervous system, increased mental workload is associated with a decrease in parasympathetic nervous system activity and an increase in sympathetic nervous system activity (Babiloni, 2019). The two systems act antagonistically, with the parasympathetic nervous system being associated with regeneration and digestion ("Rest and Digest") and the sympathetic nervous system being associated with activation and readiness for action ("Fight or Flight"). These changes in the autonomic nervous system activity can be detected by various peripheral physiological signals; for example, skin conductance (electrodermal activity (EDA, e.g., Roth, 1983), heart rate and heart rate variability (Berntson et al., 1997), and pupil dilation (Pomplun & Sunkara, 2003).

Pleasure and positive learning experiences are natural reinforcers during the learning processes that promote willingness to learn and, potentially as a consequence, learning success. Furthermore, affective-emotional states are particularly relevant, as they influence performance by means of mediators such as motivation and engagement. Due to the development of sophisticated neurophysiological recording and signal analysis methods, continuous real-time recording and decoding of emotional reactions has experienced significant progress in recent years. To decode emotions based on neuro- and peripheral physiological activity, affective-emotional states need to be operationalized first. Several approaches have been proposed in the literature. One frequently used model is the dimensional Circumplex model introduced by Russell (1980). It describes emotions with the help of the two dimensions *valence* (degree of evaluation: positive over neutral to negative) and *arousal* (degree of activation: calm to excited). While valence can be investigated via neurophysiological measurement methods, such as the EEG (Shu et al., 2018; Verma & Tiwary, 2014), peripheral-physiological measurement methods, such as the EDA and ECG, provide suitable correlates of arousal. In the past, the frontal alpha asymmetry (FAA) index has been proposed as a suitable index for decoding affective-emotional states (Smith et al., 2017). The FAA index is calculated by subtracting the EEG alpha power (i.e., oscillatory signals in the frequency range between 8 and 12 Hz) of the left hemisphere from the right hemisphere (Ahern & Schwartz, 1985). The ratio of frontal theta to parietal alpha power is used as a workload index (WL index) to detect cognitive load (e.g., Brouwer et al., 2012; Gevins & Smith, 2003).

Compared to self-reports (e.g., via questionnaires), peripheral and neurophysiological signals are stated to be more objective and unbiased when detecting cognitive and affective-emotional states. Bias in self-reports and other more subjective measures might among others occur due to social desirability or limitation of language (e.g., Nisbett & Wilson, 1977; Scherer & Ceschi, 2000).

However, especially in naturalistic settings, outside the controlled laboratory context, cognitive and affective-emotional states rarely occur separately. They are rather intertwined and interdependent (e.g., Cromheeke & Mueller, 2014; Ihme et al., 2018; Seleznov et al., 2019). In everyday life, we are confronted with complex, (socio-) emotional stimuli, demanding our cognitive resources like attention (e.g., a crying baby in a home office or laughter in an open-plan office). Previous research has shown impairing effects of task-irrelevant emotional distraction on cognitive load and working memory performance (Cromheeke & Mueller, 2014; Dolcos & Denkova, 2014; Iordan et al., 2013). There seems to be a relationship between the degree of cognitive load and affective-emotional processing. When studying interacting cognitive and affective-emotional states, identifying the neural dynamics and networks involved in order to adequately describe the interaction is a major challenge that requires further research (Morawetz et al., 2020; Okon-Singer et al., 2015; Seleznov et al., 2019; Zinchenko et al., 2020). Machine learning (ML) approaches may potentially provide a tool to identify informative correlates that decode complex cognitive and affective-emotional states and their interaction (e.g., King & Dehaene, 2014).

1.4. Neurofeedback in adaptive tutoring systems

When using neuro-adaptive systems in naturalistic applications, there are some factors that significantly influence effectiveness and acceptance: (1) feedback regarding the recognized states, (2) its perceived appropriateness, and (3) the reliability of the system. Thus, how learners perceive and evaluate feedback from neuro-adaptive tutoring systems is strongly influenced by trust: previous research has shown that trust in an agent or system is strongly affected by its reliability in task performance and negatively correlated with perceived errors of the automated system (Chen et al., 2018; Master et al., 2005). Consequently, acceptance and trust in a system are related to the perceived accuracy of the feedback and the subjective tolerance for error of the users. Alder and Ambrose's (2005) research examined the effect of perceived accuracy, fairness of feedback, and control over feedback (e.g., frequency of feedback) on satisfaction and engagement as well as behavioural measures. The authors reported that the perceived appropriateness and accuracy of feedback are critical, as these factors influence the impact of feedback on performance, attitudes toward the system, and its perceived usefulness. Using EEG, the responses evoked by the feedback can be explored in terms of Event-Related Potentials (ERPs) and used to automatically improve the feedback of the neuro-adaptive tutoring system (Ferrez & Millan, 2008; Mattout et al., 2015). ERP responses differ depending on whether feedback is perceived as appropriate or not. Two ERP responses are indicators of mental adjustment between internal and external representations and, thus, erroneously perceived feedback (Pfabigan et al., 2011): First, a negative deflection approximately 250 ms after the onset of the feedback (i.e., the Feedback-Related Negativity, FRN, which is comparable to the Error-Related Negativity) and second, a positive deflection after approximately

300 ms (e.g., P300). The indicators represent the internal process that the person perceives a discrepancy between expected and experienced feedback. To reduce the discrepancy in future interactions, expectations are adjusted based on experience.

In this paper, we present a neurophysiological-based approach to continuously capture learners' cognitive and affective-emotional states by measuring and decoding brain activity using a passive EEG-based BCI. The described research vision of a closed-loop neuro-adaptive tutoring system allows the system to learn from and adapt to detected mental states estimated from neurophysiological activation patterns.

We focus on the following research questions: (1) How well can we decode the interaction of mental states using theoretically supported correlates? (2) Can we predict subjective appraisal using neurophysiological correlates?

In a second study, we investigate (3) what effect the feedback of recognized cognitive and affective-emotional states has on performance (i.e., reaction time and accuracy). In this study, we focus on two aspects: (a) the effectiveness and assessment of unreliable feedback examined using either legitimate (consistent with the experimental condition) or inadequate (inconsistent with the experimental condition) feedback (Enriquez-Geppert et al., 2017; Logemann et al., 2010) and (b) the detection of neural correlates associated with erroneous feedback.

2. Methods

In the following, two validation studies and their results on EEG-based continuous recognition of cognitive and affective-emotional states are presented.

2.1. Sample

Eight participants participated in the first study (three women; M = 23 years; SD = 1.12; we used data from five participants for the decoding due to strong artifact in the remaining three participants) and another seven participants participated in the follow-up study (four women; M = 25.48 years; SD = 2.66). The purpose of the first study was to develop a method for continuous estimation and visualization of mental states. In the second study, we examined the effect of continuous feedback of recognized states on performance. Participants had corrected or normal vision and reported no psychiatric or neurological disorders. The study was approved by the Ethics Committee of the Medical Faculty of the University of Tübingen (ID: 827/2020BO1) and preregistered on OSF (osf.io/gnst5). Prior to the study, participants signed an informed consent form according to the recommendations of the Declaration of Helsinki.

2.2. Experimental design and procedere

At the beginning of each session, a three-minute resting state measurement of the EEG signals was performed. During the resting state recording participants had their eyes open and fixated on a crosshair positioned in the centre of the screen. Afterwards, participants performed arithmetic tasks requiring the addition of either low, 1-digit numbers (low working memory load, LWML) or larger, 2-digit numbers (high working memory load, HWML). The participants had to add up three consecutive numbers while updating and retaining the intermediate result in their memory. At the same time, affective-emotional states were induced by auditory sounds with negative (Low Valence, LV), neutral (Neutral Valence, NV), or positive (High Valence, HV) content from the International Affective Digitized Sounds (I-ADS) database (Bradley & Lang, 2007). This results in a 2 × 3 factorial study design with the cognitive conditions LWML and HWML and affective-emotional conditions LV, NV, and HV.

In the first study, participants rated the sounds after each presentation in terms of subjectively perceived valence using the Emoij-Grid (Toet & van Erp, 2019). After completing three consecutive arithmetic operations of the same difficulty, participants were asked to rate the perceived effort using the NASA Task Load Index (Hoonakker et al., 2011). Figure 01 provides a detailed overview of the experimental procedure.

In the second trial, we no longer asked participants about their subjective evaluation of the stimuli, but instead, after completing three successive arithmetic operations, we showed them either legitimate (i.e., consistent with the experimental condition) or inadequate (i.e., inconsistent with the experimental condition) feedback related to the previous cognitive and affective-emotional states (see Figure 02). Participants could correct the rating via mouse click on the scale according to their own perception. In 80% of the runs, the feedback score was consistent and, thus, legitimate with the experimental condition; in 20%, it was inconsistent and, thus, inadequate. For example, a high recognized cognitive load was feedbacked after a simple task (inadequate feedback). After the experiment, we asked the participants in a semi-structured qualitative interview how they perceived the feedback.

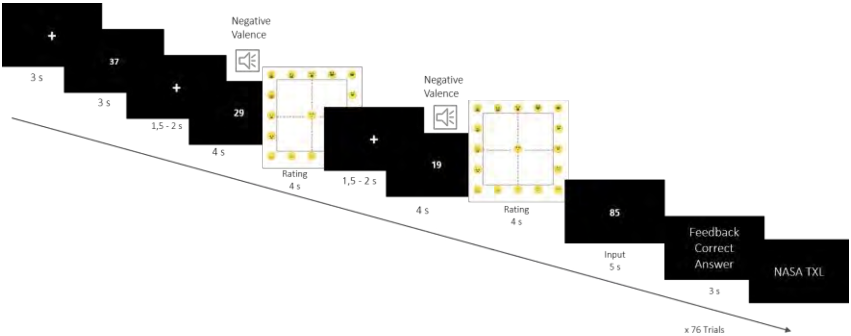

Figure 01: Experimental procedure of the first study. After each auditory stimulus and after each cognitive task, participants provided subjective ratings regarding the perceived valence and cognitive effort.

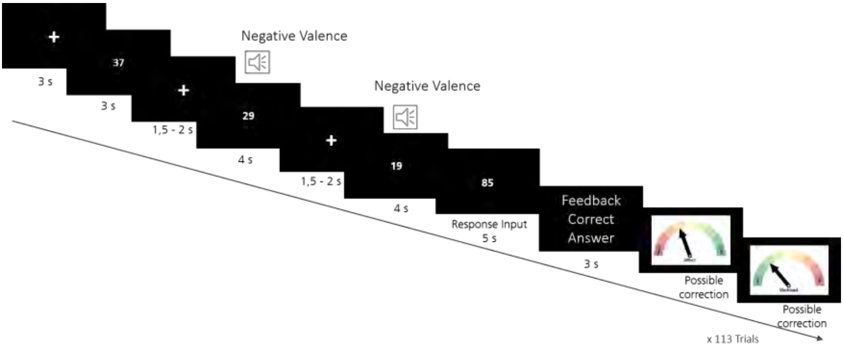

Figure 02: Experimental procedure of the second study. After each run, two scores indicating the recognized valence and cognitive effort experienced during the previous trial were presented to the participants. In 20% of the cases, the presented scores were not adequate. The participants could adjust the scores via mouse click according to their own perception.

2.3. EEG recording and analysis

EEG data were recorded according to the international 10-20 system using the Cognionics wireless EEG headset with 20 dry electrodes and a sampling rate of 500 Hz (see Figure 03).

The EEG was grounded to the left mastoid and the impedance was below 2,500 kΩ at the beginning of the experiment. During offline pre-processing, signals were decorrelated, zero-padded, and referenced to mathematically linked mastoids (Nunez & Srinivasan, 2006). A notch filter and FIR (finite impulse response) bandpass filters with cut-off frequencies of 1 and 20 Hz were applied. Then, the signal was cut into 4 s long epochs starting from the presentation of the stimuli. A 200 ms baseline was extracted per epoch from the signal before stimulus onset. Epochs that had a maximum deviation of 250 µV in one of the frontal EEG channels (Fp1, Fp2) were removed. In addition, artifacts due to cardiac and muscle activity or eye movements were removed using an independent component analysis (ICA) (Chaumon et al., 2015; Hipp & Siegel, 2013; Lee et al., 1999). The independent component analysis (ICA) computes linearly independent components (IC) from the data, which can then be classified as artifact or true EEG signal based on their topology or power spectrum. In the next step, the power in the alpha (8 - 12 Hz) and theta (4 - 7 Hz) frequency bands was calculated using the Welch method, that is a modified version of the Fast Fourier Transform (FFT).

Figure 03: State-of-the-art EEG sensors with dry electrodes, which allow easy handling during preparation.

To evaluate the ERPs for the consistent and inconsistent feedbacks, the EEG signals were filtered with an FIR bandpass filter and narrow frequency band from 0.5 to 23 Hz. In addition, smaller 1-s epochs were chosen starting from the presentation of the estimated score (i.e., the feedback). Epochs were corrected to baseline by subtracting the mean amplitude of the baseline interval (200 ms before score onset). To identify differences in ERPs between feedback conditions for valence and cognitive effort scores, we used a cluster-based nonparametric randomization approach (Maris & Oostenveld, 2007). Clusters were identified as adjacent EEG channels and time points in the epoch, using a T-value-based cluster-level threshold of $p < .01$ and a group-level threshold of $p < .05$ (two-sided).

To quantify differences between feedback conditions (consistent and inconsistent), a one-factor repeated measures analysis of variance (rmANOVAs) was used with the dependent variables (1) perceived correctness (that is, the likelihood that the person will correct the feedback score), (2) reaction time and (3) accuracy on the subsequent trial.

2.4. ML-based decoding of cognitive and affective-emotional states

For the estimation of the mental states, we used those channels and frequency bands that are proposed in the literature for the calculation of indices associated with affective-emotional and cognitive states (F3 - alpha, Fz - theta, F4 - alpha, Pz - alpha) as well as the Hjorth measures of mobility (proportion of standard deviation of the frequency spectrum) and complexity (change within the frequency band) of the respective channels as predictive features. In a second step, we corrected the hypothesized annotations (based on the experimental condition) using the subjective ratings in order to predict the subjective evaluation. In the second prediction of the subjective ratings, the same neurophysiological signals were used as features.

The conditions were classified in pairs (HV-HWML vs. LV-HWML, HV-LWML vs. LV-HWML, LV-HWML vs. HV-LWML, LV-HWML vs. LV-LWML) and in a four-class problem (HV-HWML vs. HV-LWML vs. LV-HWML vs. LV-LWML).

The following supervised ML classifiers were implemented using scikit-learn (Pedregosa et al. 2011) and explored regarding their performance: (1) Logistic Regression (LR), (2) Support Vector Machine (SVM), k-Nearest Neighbor, (4) Random Forest Classifier (RFC), (5) Gradient Boosting Classifier (GBC), and Gaussian Naive Bayes (GNB). A dummy classifier with stratification as method was trained as an empirical baseline indicating a random prediction which also considers class distributions in the data. Hyperparameters were optimized in a randomized GridSearch based on the training set and with the balanced accuracy as evaluation metric. Classification accuracy of the classifiers was evaluated within a stratified 3-fold cross-validation individually for the participants using the balanced accuracy as evaluation metric. To obtain a distribution of average classification accuracy, we used a Monte Carlo simulation (MCS) by training the classifiers 100 times, each with a new train-test split (80:20) and model initiation.

3. Results

3.1. Decoding of neural correlates for the prediction of the conditions and subjective ratings

To answer how well we can decode the interaction of mental states using theoretically supported correlates, we compared several supervised ML methods. Our results show that we were able to discriminate experimental conditions with high classification accuracy (see Table 2 and Figure 5).

	Experimental condition			**Subjective ratings**		
Classifier	2.5th percentile	Mean	97.5th percentile	2.5th percentile	Mean	97.5th percentile
LR	0.626	0.923	1	0.15	0.344	0.542
SVM	0.642	0.917	1	0.15	0.352	0.558

KNN	0.562	0.865	1	0.133	0.353	0.592
RFC	0.597	0.866	1	0.133	0.334	0.550
GBC	0.569	0.865	1	0.117	0.327	0.558
GNB	0.532	0.835	1	0.133	0.339	0.567
Dummy	0.182	0.500	0.818	0.091	0.280	0.500

Table 1: Average classification accuracy based on the test set of classifiers compared to an empirical baseline. Left: Prediction of the experimental condition. Right: Prediction of the subjective ratings.

Thereby, the accuracy measures of the selected classifiers (LR, SVM, KNN, RFC, GBC and GNB) are significantly above an empirically estimated chance level (dummy classifier). The classifiers do not differ significantly in their classification accuracy (see Table 1). In a next step, we wanted to predict the subjective assessments, that are the subjective ratings, using the same algorithms and neurophysiological correlates. Interestingly, the classification accuracy drops to a chance level when the annotations are corrected based on the subjective ratings. Thus, influences not represented in the neurophysiological signals seem to affect a subjective assessment of experienced stimuli and perceived states.

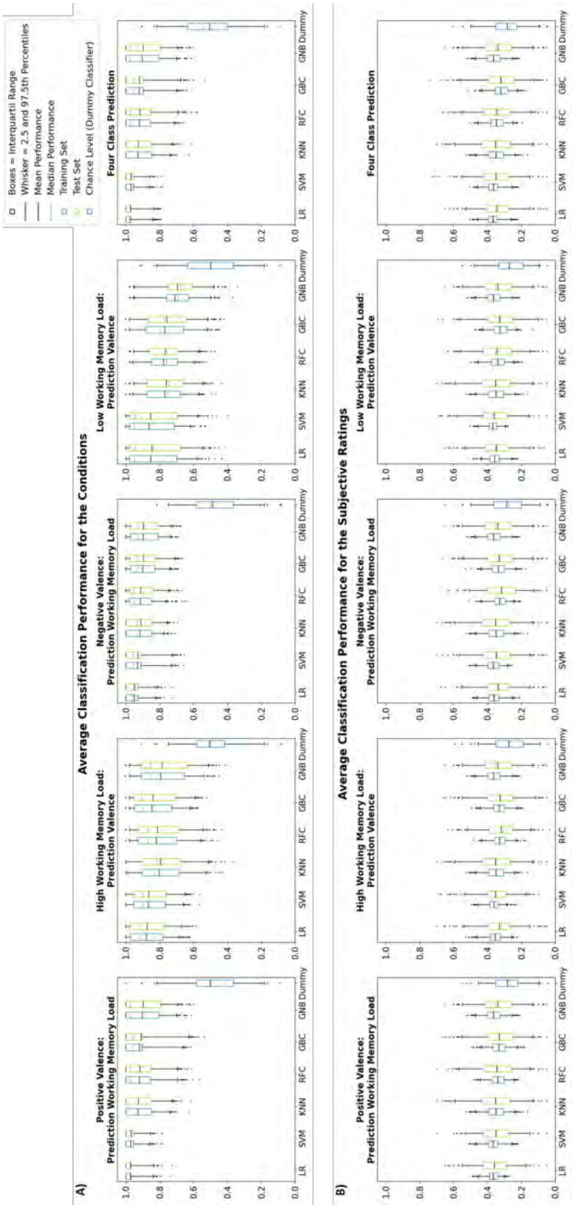

Figure 05: Average classification accuracy of the training set (green) and test set (light green) of participants and iterations compared to an empirical baseline (dummy classifier; blue). 2.5th and 97.5th percentiles of the simulation with 100 iterations. Top: Prediction of the experimental condition. Bottom: Prediction of the subjective ratings.

3.2. Influences of consistent and inconsistent feedback on performance-related measures

In a second study, we examined the effect of consistent and inconsistent feedback regarding recognized cognitive and affective-emotional states on performance (i.e., reaction time and accuracy). With regard to perceived accuracy, participants corrected inconsistent feedback of recognized values significantly more frequently, $F(1, 6) = 30.82, p < .001, p\eta^2 = .84$ (cognitive effort score) and $F(1, 6) = 5.14, p = .064, p\eta^2 = .46$ (affective-emotional state score). Inappropriate, inconsistent feedback had no significant effect on performance-related measures in the subsequent run. Experimental condition (e.g., task difficulty) had no effect on perceived accuracy of feedback and likelihood of correction. Analysis of the neurophysiological ERP responses did not identify significant clusters describing the difference between consistent and inconsistent feedback. In the semi-structured interviews, participants reported that they perceived the feedback scores as positive and interesting, but sometimes irritating. The design and feedback format, in the form of a barometer, was rated as appropriate and appealing. About half of the participants reported that they had not voluntarily used the feedback to change their strategy or behaviour. One person reported that he or she was motivated by the score and perceived it as promoting regarding the concentration. Some participants expressed a need for detailed clarification of the underlying calculations and measures used for the scores.

4. Discussion

Our results show that machine learning algorithms can distinguish different affective-emotional states and levels of cognitive load. There was no difference between the algorithms used. The finding that the hypothesized induced difficulty and valence (based on the experimental condition) can be learned and predicted with high accuracy from the neurophysiological data is of particular relevance; however, we could not predict the subjectively perceived difficulty and valence reported by participants in the questionnaires. This observation highlights the importance of objective methods for learner state recognition. Modulating effects, such as social desirability, processes of cognitive dissonance for self-image maintenance, or the capacity and ability to reflect on past experiences, can bias the self-assessment. These modulations are not represented in the neurophysiological signals measured simultaneously during the task and stimulus processing. The observed discrepancy between neurophysiological-estimated and subjectively perceived states could have relevant effects on the learner's trust in and, thus, the acceptance and effectiveness of a neuro-adaptive tutoring system. Future research on the integration of this discrepancy and the design of a tutoring system that is experienced as adequate is necessary. Furthermore, further research is needed to identify a suitable ground truth and associated calibration tasks that allow training of a tutor system.

For the implementation of neuro-adaptive tutoring systems in naturalistic environments with the goal of a high learner's acceptance of the systems, accuracy, and reliability of the online estimation of cognitive and affective-emotional states is of great importance. Even though offline methods could distinguish different affective-emotional states and levels of cognitive load with high accuracy, online state detections still showed a large variance in the accuracy of the detected states. To assess negative evaluation of inaccurate feedback, we examined the effect of inconsistent, inadequate as well as consistent, accurate feedback on a neural and behavioural level. Interestingly, we did not observe a negative effect of inconsistent or inaccurate feedback on participants' performance. However, this could be partly due to the small sample size of the exploratory study.

5. Conclusion

Our neurophysiological-based approach to capture learners' affective-emotional and cognitive states contributes to the development of closed-loop neuro-adaptive tutoring systems. These systems allow to monitor the learner's state, provide feedback, and adapt their system and learning parameters to individual abilities, needs and currently available resources (e.g., in terms of concentration). Optimal adaptation to the learner can contribute to an effective and positive learning experience. The design and validity of feedback is a major challenge for the effectiveness of feedback on performance-related measures. Therefore, influences of feedback formats should be explored in future research. In a next step, we aim to develop a methodology for robust detection and prediction of affective-emotional and cognitive states of learners during the learning and training session. This will require appropriate signal processing and artifact cleaning steps (filters, component analyses, etc.) to pre-process the signals, as well as computationally efficient, robust classifiers for real-time prediction of the experienced mental states (see Figure 06).

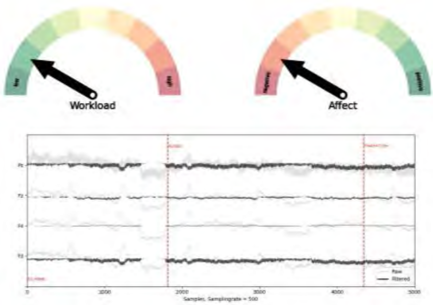

Figure 06: Outlook of a neurophysiological-based learner state recognition during a learning or training task.

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Analysis of supply-chains in the circular economy by means of VSM

Jeff Mangers, Peter Plapper

The Circular Economy (CE) concept aims to close resource loops and keep resources in the system for as long as possible at the highest utility level, without neglecting the goals of sustainable development. This paradigm shift from a finite and linear to a circular economy is however only possible if systems can be viewed as holistic overall systems. Thus, preventive problems can be identified and located as early as possible and counteracting measures initiated.

This paper presents a new value stream mapping (VSM) model to consider interrelated processes in a holistic manner, regarding the requirements of CE. To do so, one macro-level to consider interrelated company relationships together with a respective micro-level to consider the individual company specific processes are elaborated. The degree of circularity is determined based on the 9R framework and new visualizations and measurement indicators are added at the different levels. This new model helps to mainly identify hurdles at a product's end-of-life, which are preventing a circular flow of resources, worth sharing with the responsible of a product's beginning-of-life. The model itself is validated by an extensive cross-company PET-bottle case study in Luxembourg.

1. Introduction

The Circular Economy (CE) concept aims to close and slow resource loops (Moraga et al. 2019) and avoid waste (Di Maio et al. 2017), without neglecting the goals of sustainable development (Azevedo, Godina, and Matias 2017). Recently, the concept has received encouraging attention among researchers and economists (Merli, Preziosi, and Acampora 2018) as a suitable solution to move from the finite linear economic concept to a more sustainable one (Bocken et al. 2017). In addition to the lack of an internationally accepted definition for CE (Kirchherr, Reike, and Hekkert 2017), there are a number of other barriers and hurdles (e.g., technical, cultural, market, and regulatory barriers) (Grafström and Aasma 2021) that prevent a successful shift from a linear to a circular economy. Generally speaking, this paradigm shift is only possible if systems can be viewed as holistic and thus preventive problems can be identified and located as early as possible. Methods such as life-cycle assessment (LCA) or material flow analysis (MFA) are

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better suited for static considerations and not for the desired holistic visualization, which is why a new visualization method is needed.

Value stream mapping (VSM) is a commonly known lean methodology (Mangers, Thoussaint, et al. 2020) that is used to visualize the current state of material and information flows within an organization in order to find weaknesses and improve process flows (ISO 22468 2020). The aim of this paper is to present a new VSM model that can assess and visualize interrelated processes related to the circular economy at macro (supply chains) and micro (individual company) levels. To this end, new indicators and visualizations are incorporated into the traditional VSM model that provide a new circular perspective on resource flows within supply-chains (SCs) and within companies.

The assessment indicators are divided into direct (CE) and indirect (sustainability - environmental, economic, and social) indicators. The selection refers to indicators of sustainability VSMs as well as a systematic literature research regarding CE indicators (182 in total, future publication on this is planned). The data collection is an important and elaborate part of the VSM analysis, which takes place during a company visit. The first step is to try to understand the general process flow before process specific data is recorded. Company critical data must not be shared with other SC partners under any circumstances.

The goal of the macro-level visualization is to provide a holistic overview of the entire supply chain. To illustrate the circular value of the targeted cycle, the 9R framework (e.g., R3-reuse, R8-recycle, etc.) (Kirchherr et al. 2017) has been inserted as a value ladder and thus helps to make the value of each company easily recognizable. The 9R framework can be understood as the 'how-to' of CE, with as the main feature a hierarchy, where the first R (R0-refuse) is considered a priority over the second R (R1-rethink) and so on. The additional data fields provide insight into the respective company consumption as well as the total consumption. On a micro level, the adapted visualization is mainly used to illustrate the internal resource flows. Thus, not only the main material flow is shown, but also additional flows such as the packaging or additional material flow. Resource in- and outflows can be an indication for potential CE improvements, mainly with regard of waste flows. The data fields provide an insight into the respective process as well as the total consumption.

2. Methodical procedure

Figure 1 visualizes the methodological approach of this paper.

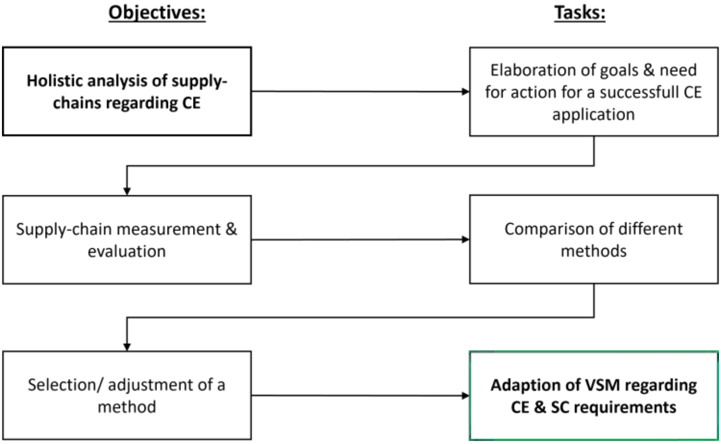


Figure 1: Methodical procedure

The left side lists the main goal (top left) and the intermediate goals, and the right side lists the intermediate task and the main task (bottom right). Each given goal contains a corresponding task. The main objective was a holistic analysis of supply chains with respect to their circularity. For this purpose, three CE objectives, as well as two application fields with a need for action were elaborated (Mangers, Minoufekr, and Plapper 2021). The three main CE objectives are as follows:

1. Close and slow loops (Sensu stricto) (Moraga et al. 2019),
2. Minimize waste (Morseletto 2020),
3. Sustainability (Sensu latu) (Kirchherr et al. 2017)

with the two fields of action:

1. Identifying the needed collection, sorting, and R-infrastructure,
2. Developing circular product design guidelines.

This results in the need for an improved information exchange between end-of-life (EOL) and beginning-of-life (BOL), which is required to initiate a successful paradigm shift. This is set as the objective of the holistic VSM visualization.

As an intermediate goal based on this, the measurement and evaluation of supply chains with respect to their circularity is set, which entails a comparison of different methods (to be explained in a future publication), with the aim of finding a suitable method. VSM was selected, with the requirement and main task of this paper to adapt the VSM method regarding CE and SC aspects. For this purpose, first an extensive literature review (inspired by Fink (Fink 2019) was performed regarding the already existing visualization and design possibilities using VSM. The results are shown in Table 1.

The research methodology is analytical and the case study structure is based on Yin methodology (Yin 2018). The data collection was conducted, during 10 different company visits, all part of a supply chain network of a PET bottles in Luxembourg.

The next section looks at the theoretical background of VSM before Chapter 4 addresses the macro- and micro-level results. The final chapter summarizes the main points and provides an outlook for future work.

3. Theoretical background

The basic VSM concept was developed by (Rother and Shook 1999) and further details regarding defined calculation procedures were provided by (Erlach 2013). To ensure a common understanding of the most important VSM symbols, parameters and calculation procedures, VSM has been standardized by ISO (Mangers, Oberhausen, et al. 2020).

Basically, VSM visualizes the flow of materials and information within a company, focusing on time. Beyond that, however, other fields of application have been pursued, and the consideration of CE is not an entirely new idea. (Edtmayr, Sunk, and Sihn 2016) incorporated three reuse cycles (reuse, recycle, recovery and disposal) for waste materials into VSM. (Galvão et al. 2020) focused mainly on connecting value streams within circular business models and their ecosystems rather than measuring the circularity of value streams. (Hedlund et al. 2020) explored how companies and industrial systems and networks can use value stream mapping as a tool to improve sustainability and accelerate the shift towards a green, circular economy. However, none of the mentioned authors focused on measurement and evaluation, as well as holistic analysis of CE using VSM.

In addition, much emphasis has recently been placed on linking VSM with sustainability (Edtmayr et al. 2016) as well as other complementary indicators. Table 1 summarizes the indicators currently included in VSM.

Category	Sub-category	Metrics, example	Unit	Reference
Emissions (env.)	Air-emissions	Nitrogen oxides, heavy metal	kg	(Paju et al. 2010)
	Environment	Multidimensional, connections within the SC	dif.	(Lorenzon dos Santos et al. 2019)
	Water-emissions	Chemical oxygen demand	kg	(Paju et al. 2010)
Energy (env.)	Energy type/ -consumption	Electricity, heat, cooling	kWh, MJ	(Paju et al. 2010)

	Dual energy	Idle processing run	kWh	(Müller, Stock, and Schillig 2014)
Material (env.)	New material	Steel, packaging material	kg	(Paju et al. 2010)
	Recyclate	rPET	kg	(Garza-Reyes et al. 2018)
	Additional material	Lubricating oil, compressed air	m3, kg	(Paju et al. 2010)
	Waste	Waste oil, waste materials	kg	(Paju et al. 2010)
	Scrap	Quality problems	kg, pc	(Edtmayr et al. 2016)
Transport (env.)	Internal transportation	Between processes	m, CO2	(Garza-Reyes et al. 2018)
	External transportation	Between production plants	m, CO2	(Garza-Reyes et al. 2018)
Water (env.)	Water consumption	Cleaning water	m3	(Faulkner and Badurdeen 2014)
Data (eco.)	Industry 4.0	Multidimensional	dif.	(Huang et al. 2019)
	Information flow	Information up- and download	dif.	(Mangers, Thoussaint, et al. 2020; Meudt, Metternich, and Abele 2017)
	Supply-chains	Multidimensional	dif.	(Matt, Krause, and Rauch 2013; Megayanti, Anityasari, and Ciptomulyono 2018)
Costs (eco.)	Unit costs	Material-, energy costs	€	(Paju et al. 2010)
	Investment costs	Machine, robot	€	(Paju et al. 2010)
Production (eco.)	Efficiency	OEE	%	(Dadashnejad and Valmohammadi 2019)
	Make-to-order	Takt time	s	(Mudgal, Pagone, and Salonitis 2020)
	Multilayer	Multidimensional	dif.	(Lourenço et al. 2016)
	Quantity	Pieces	pc	(Paju et al. 2010)
	Time	Process time, lead time	s	(ISO 22468 2020)
Surround-ings (soc.)	Employees	Number of work-ers, work loss	#	(Paju et al. 2010)
	Customer service	Number of com-plaints	pc/ year	(Paju et al. 2010)
Load (soc.)	Working environment	Physical Load Index (PLI)	#	(Faulkner and Badurdeen 2014)(Kuhlang et al. 2014)
	Risk categories	Electrical, chemicals, pressure, speed	#	(Faulkner and Badurdeen 2014)
	Noise level	Machinery noise	dB	(Vinodh, Ben Ruben, and Asokan 2016)
Conversion factor	CO2-equivalent	kWh to CO2-eq	CO2-eq.	(Edtmayr et al. 2016)
	Scaling factor	Compensation small numerical value	#	(Roosen and Pons 2013)
Simulation	DES & LCA	Multidimensional	dif.	(Paju et al. 2010)

	Simulation product development	Time, share	s, %	(Ciarapica, Bevilacqua, and Mazzuto 2016)

Table 1: Summary of indicators currently included in the VSM, with focus on sustainability (env.: environmental, eco.: economic, soc.: social, add.: additional)

To provide a holistic view, VSM will be applied at four different levels in the following (Oberhausen 2018; WBCSD 2018):

1. Nano: smallest possible level of analysis at which products and components are located.
2. Micro: Level at which companies and consumers stand
3. Meso: level that represents cross-industry and cross-company (intercompany) networks
4. Macro: highest level of analysis, where cities, countries and international agencies are located.

The following articles were used as references for mapping supply chains using VSMs: SCs-VSMs (Anderson 2017; Costin-Weiterschan/ Matiou 2017; Suarez-Barraza et al. 2016), sustainable SC-VSMs (Megayanti et al. 2018) and circular SC-visualizations (González-Sánchez et al. 2020).

More detailed explanations of the individual values of the 9R framework, can be seen in Figure 2. The hierarchy refers to the waste/value hills, which establishes a priority order of what represents the best overall environmental option in waste legislation and policy (European Parliament and Council of the European Union 2008).

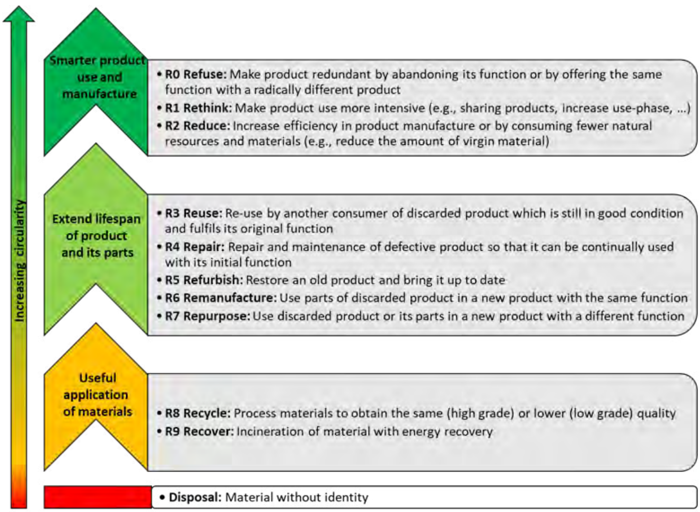


Figure 2: 9R framework, adapted from (Kirchherr et al. 2017)

The overall goal of CE, which aims to maintain products, components, and materials at their highest utility and value at all times, is divided into a technical and biological cycle. An often used representation of the 9R framework in relation to the two cycles is the butterfly diagram from the Ellen MacArthur Foundation (EMF 2015), which can be seen in Figure 3.

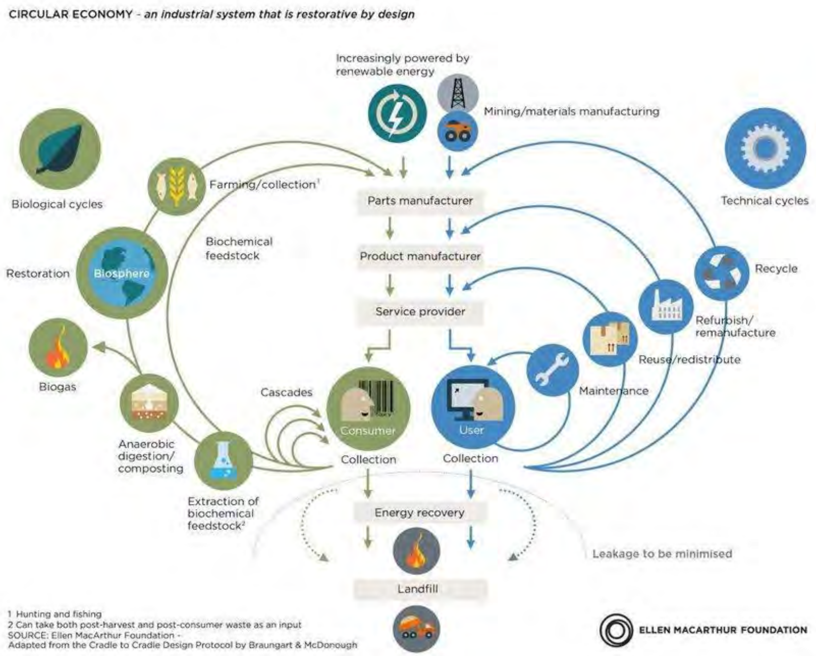


Figure 3: Butterfly diagram, sketch of a CE-technical & biological cycle (EMF 2015)

In the next section, the aforementioned findings are integrated into a holistic VSM model that meets the requirements of CE.

4. Results

The results are presented in a top-down approach. This means that first the new VSM model is explained on a macro-level (whole SC) before the model is deepened on a micro-level (company). The interrelationships and representations are illustrated by means of an extensive case study of PET-bottles within Luxembourg.

4.1. Macro-level analysis

The macro VSM visualization is quite different from traditional VSMs. The main issues were how to map a circular flow of resources and how to insert a CE value representation. Both goals were achieved through inspiration from the Swim-Lane alternative (see ISO 22468:2020, p. 30) and incorporation of the 9R framework. Each level of the Swim-Lane diagram represents a particular CE value, and the lowest level defines the overall VSM value. The 9R framework is included as a vertical value ladder on the right side of the diagram, ranging from R0 (highest value) to R9 (lowest value).

Since the three highest Rs (refuse, rethink, and reduce) are only achievable through adaptive design, they are shown as one value at the design level. The second value is the actual use phase, where the product has its highest value. All other Rs are included until the last one, disposal, which has no CE value and should be avoided.

Each SC partner is visualized as a process box with a corresponding data box containing information from the micro-analysis. The OEM is visualized as ISO 22468 customer and the direct (e.g., PET-bottle, HDPE closure) and indirect (e.g., additional packaging film) supplier as ISO 22468 supplier. The user has a new symbol. Depending on the respective level, different information is displayed within the data boxes (see Figure 5 & Figure 6). As the total value is defined during the collection and sorting process (compare glass and PET disposable bottle), this process ranges from R3 to disposal. Resource flows between two SC partners are color coded and complemented by a corresponding transport symbol. A final addition is the inclusion of two information flows, D- (active in product/process design) and R-information flow (active in resource take-back), as well as the inclusion of certain basic process characteristics (e.g., functional unit, material, etc.) that define the product under consideration. This is an important addition as it helps to locate responsibilities within the supply chains and represent them in a simple way. This can be beneficial to identify missing links and information exchanges between companies active at the beginning of the product life cycle (BOL) and those active at the end of the product life cycle (EOL). For example, in the case study cited, it is evident that there is no exchange of information between the EOL and BOL that ensures that the design of the bottles produced meet the reintroduction criteria. Thus, during sorting, the bottles may end up in a resource stream for another product (e.g., green: clothing industry).

The selected indicators are divided into two major subgroups. The first subgroup relates to CE (direct) and the second to the three sustainability pillars (environmental, economic, and social - indirect), shown in Figure 4. The indicators are interrelated (e.g., electricity consumption and transport volumes & distance are converted to CO_2-eq), as well as from one level to the levels above. The division of indicators into direct and indirect is based on the three main CE goals mentioned in chapter 2. The indicators were partly selected from Table 1 and from a list of 182 CE indicators obtained from a systematic literature review.

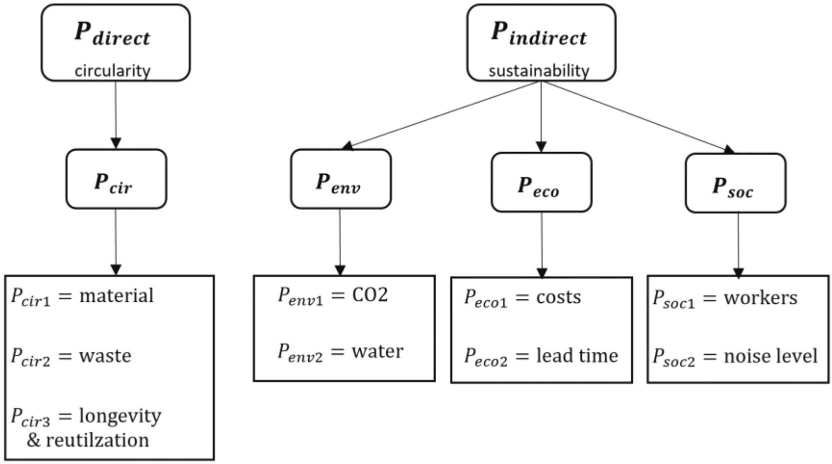


Figure 4: Subdivision of indicators

However, since there is currently no internationally accepted definition of CE, let alone a list of indicators that measure the circularity of products or supply chains, the selected indicators are subject to change. In order to keep the number of indicators manageable and based on the product requirements, the selection in this case fell on the nine indicators shown in Figure 4.

Generally speaking, this new representation helps to depict and view supply chains holistically. It allows to better understand the interrelationships within a supply chain and to trace the connections and dependencies among the individual companies. The data summary of the individual SC partners makes it easy to see which company has the greatest potential for improvement (e.g., if the goal is to improve CO2 emissions, it makes sense to start with the company responsible for the highest CO2 emissions). The color coding also makes it easy to identify the individual resource flows.

Figure 5 visualizes the adapted VSM on a macro level using a PET-bottle case study. The SC partner (water bottler) marked in blue is explained in more detail at the micro level and the data is anonymized. In this example, the dashed line between 'Collection & Sorting' and 'Flake-prod.' indicates that recycling of the material is theoretically possible but will not be the case due to the color sorting and associated material flows in Luxembourg. Thus, while the PET-bottle itself consists of recycled material, due to the color, reuse within the packaging industry will not be the case. This is mainly due to the lack of information exchange between EOL and BOL.

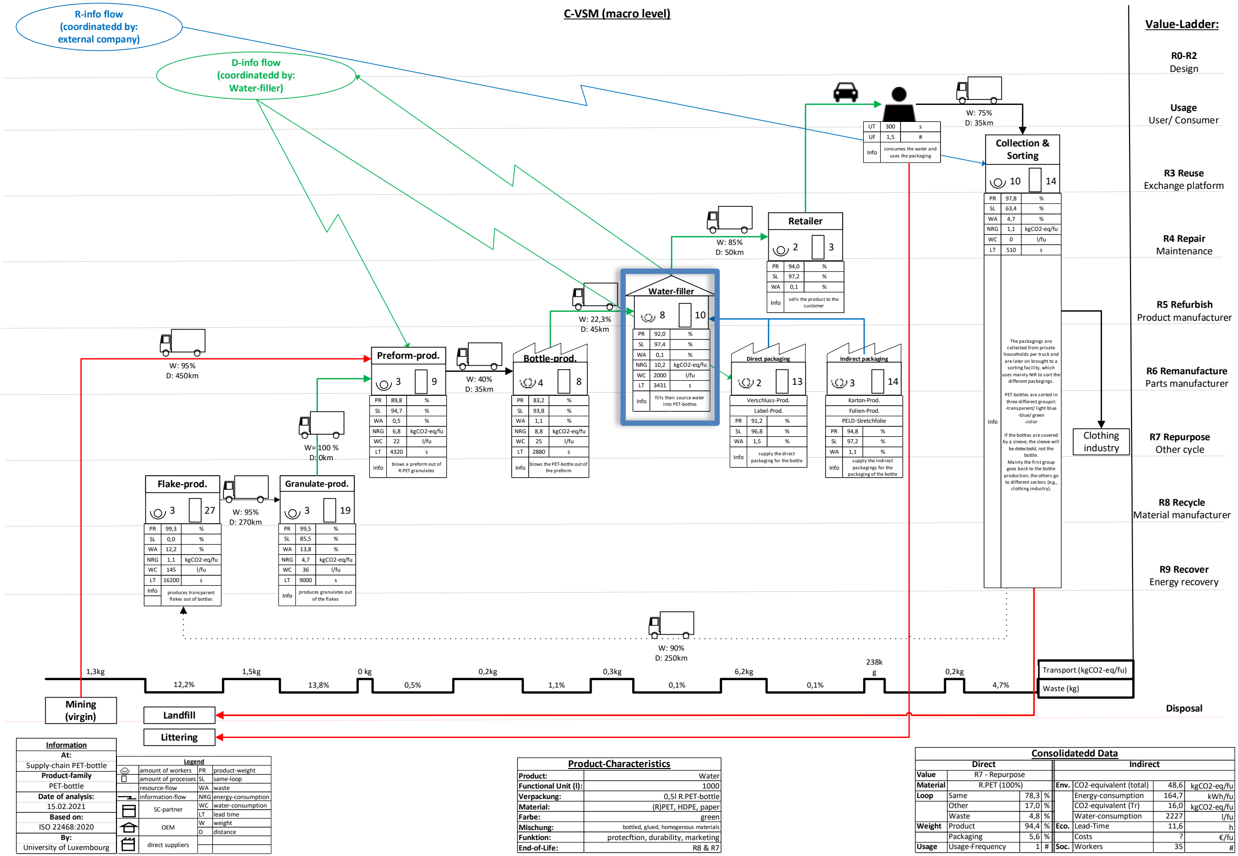


Figure 5: VSM at macro-level

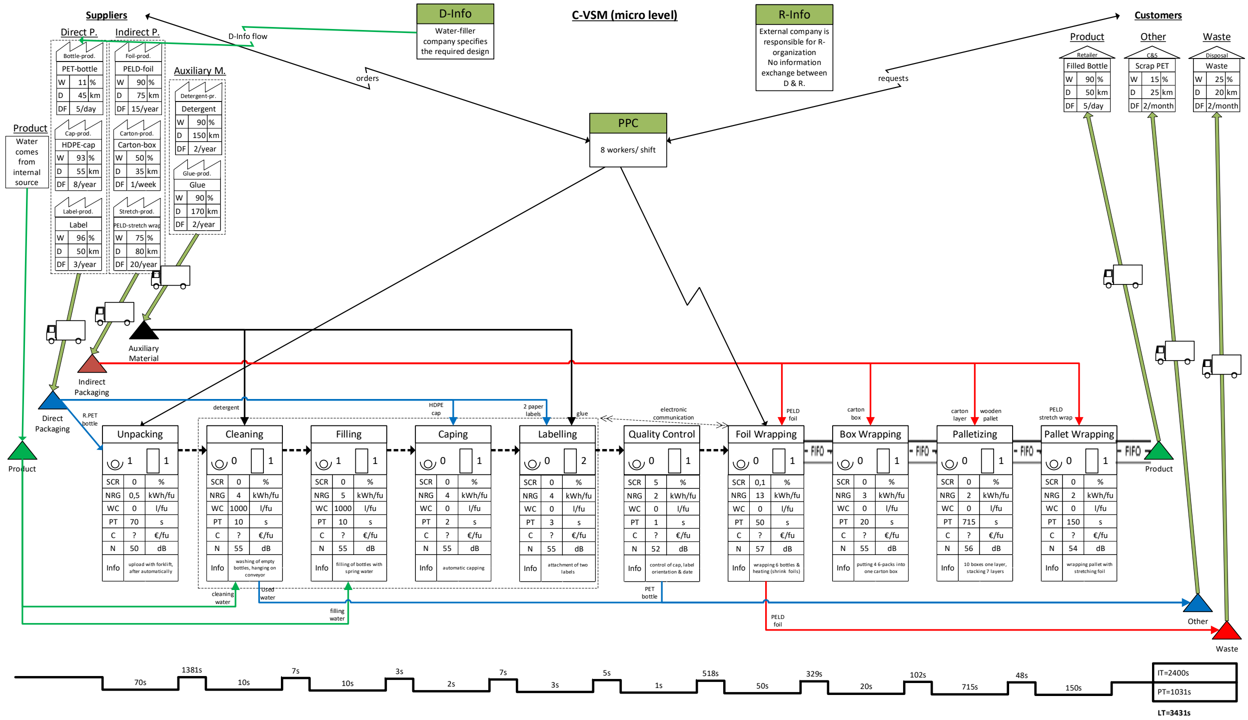
4.2. Micro-level analysis

The micro VSM differs slightly from the traditional VSM. The main differences are the new indicators and the visualization of additional material flows. The material flows, like the suppliers, are divided into four different groups, which are color-coded. The first group represents the actual product (e.g., water; green), the second group the direct inputs (e.g., bottle, cap, and label; blue), the third the indirect inputs (e.g., additional film packaging; red) and auxiliary materials (e.g., glue; black). Output streams and customers are also divided into three groups: resources that remain in the same loop (e.g., packaged bottles; black), resources that go to other loops (e.g., PET waste; blue), and waste (e.g., film packaging; red). The traditional information flow is kept, and the D and R information flow are added in addition to see if there is a connection between the two.

Just as at the macro-level, the indicators used are divided into two main groups (direct and indirect, see Figure 4) and are illustrated in Figure 6 using the example of a water-filler within the case study. The abbreviations of the individual indicators are explained in the appendix. There are relationships between micro and macro data and the indicators are mostly based on a functional unit. CO2 equivalents are calculated using national conversion factors and are used as a rough guide. The data itself and the names are fictitious in order not to share critical information.

The micro-level representation is structured in such a way that the results of the analysis can flow directly into the higher-level macro-level diagram. Thus, the indicators of the individual processes are added up to an overall value for the company and, if necessary, converted (e.g., electricity consumption to CO2-eq.). This result can thus be included directly in the macro-level view, while retaining the advantages of a traditional VSM and extending them through holistic adjustments.

In the case study example, it can be seen that the 'Foil Wrapping' process (high temperature application) is responsible for much of the energy consumption, although this is an indirect packaging process. The loops and weights within the summary contain interesting information. Here it can be seen that there is a small amount (2.5%) of scrap which is inserted into the national 'Collection & Sorting' and only a very small amount (0.1%) cannot be reused and is designated as waste. In the weight breakdown, it can be seen that packaging (direct and indirect) represents only a small portion (8%) of the total weight. This is a significant difference compared to a glass bottle, where the packaging share was over 40% for the same company.



Information Database
At:
Water-filler
Product-family:
PET-bottle
Date of analysis:
15.02.2021
Based on:
ISO 22468:2020
By:
University of Luxembourg

Legend			
	amount of workers	W	weight
	amount of machines	D	distance
	ressource-flow	DF	delivery frequency
	information-flow	SCR	scrap-rate
	proccess	NRG	energy consumption
		WC	water-consumption
	customer	PT	process time
		C	costs
	supplier	N	noise level

Product-Characteristics	
Product:	Water
Functional Unit (l):	1000
Packaging:	0,5l R.PET-bottle
Material:	(R)PET, HDPE, Paper
Color:	green
Mixing:	bolted, glued, homogeneous materials
Function:	protection, durability, marketing
End-of-Life:	R8 & R7

Consolidated Data							
Direct				Indirect			
Value	R8-Recycle						
Loop	Same	94,9	%	Env.	CO-equivalent (total)	16,9	kgCO2-eq/fu
	Other	5	%		Energy-consumption	47,50	kWh/fu
	Waste	0,1	%		CO2-equivalent (Tr)	6,64	kgCO2-eq/fu
Weight	Product	92	%		Water-consumption	2000	l/fu
	Direct Packaging	4,5	%	Eco.	Lead-Time	3431	s
	Indirect Packaging	3,5	%		Costs	?	€/fu
	Auxiliary Material	0	%	Soc.	Workers	8	#
Usage	Usage-Frequency	1	#		Average noise	54,4	dB

Figure 6: VSM at micro-level

5. Discussion & Outlook

In this paper, a new VSM visualization at macro- and micro-level related to CE has been presented. Even though there have been first attempts to include CE in VSM, none of the authors applied the traditional VSM method to visualize and evaluate the current state of resource flows according to CE, which is an important step for later analysis and optimization. The current state mainly helps to visualize possible weak points.

In a first step, the new VSM visualization has been applied within an extensive packaging use case and focuses primarily on one main resource flow. Therefore, the model should be verified in other use cases and further research is needed to focus on more than just the main resource flow. Currently, MS-Visio is used to draw the VSM and a connection to MS-Excel is included for data processing. As this is not an ideal solution especially in terms of analysis and optimization, this should be changed in the future. In addition, data collection is currently very time-consuming, as the individual pieces of information must be collected during visits and are often not available (e.g., electricity consumption of individual processes). This could be facilitated in the future by independent data entry by the companies. In addition, this would enable time series recording, which is currently seen as one of the main criticisms of VSM analyses.

Overall, this work has presented a valuable extension of the current VSM application to help make the shift from a linear to a circular economy by considering interrelated process chains in a more holistic manner. Additionally, this use case of a complete SC is innovative and can help to further promote the importance of a holistic approach in analyzing current CE problems.

The set goal of evaluating and analyzing interrelated process chains in terms of CE at different levels was met. The indicators shown in Figure 5 and Figure 6 were chosen with respect to this specific case study in order to best address the needs of the industry. For other studies, other indicators may need to be chosen.

The current state of this research is mainly concerned with recording the current state of interconnected SC with respect to CE. Future research will focus primarily on using the knowledge gained and focusing more specifically on analysis as well as optimization. This is to be achieved primarily through improved communication and information exchange between the EOL and the BOL, thus enabling a holistic improvement of current value streams. The aim should be to transfer the EOL decision-criteria (e.g., green PET-bottle goes to clothing industry, sleeve prevents a successful detection of the bottle material, etc.) towards the BOL, so the design-phase. This way, the design can be better adapted towards the needs and capabilities of the EOL. This should not only be the case for packaging, but also all other kind of products.

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Appendix

Abbreviation:	**Meaning:**
BOL	beginning-of-life
C	costs
D	distance
DF	delivery frequency
dif.	Different
EOL	end-of-life
fu	functional unit
IT	idle time
LT	lead time
N	noise level
NRG	energy-consumption
OEM	original equipment manufacturer
PR	product-weight
PT	process time
R-infrastructure	This term is used for any infrastructure needed to reintroduce resources into a particular cycle.
SCR	scrap-rate
SL	same-loop
W	weight
WA	waste
WC	water-consumption
	number of workers
□	macro: number of processes, micro: number of machines

Table 2: Abbreviations of the individual indicators

Human-Centered Development and Evaluation of an AR-Assistance System to Support Maintenance and Service Operations at LNG Ship Valves

Hendrik Stern, Rieke Leder, Michael Lütjen, Michael Freitag

1. Introduction

Liquified natural gas (LNG) is used for transportation, due to the significantly higher density in the cryogenic state compared to normal natural gas. LNG can be transported to or from regions efficiently that cannot be connected to pipeline systems, e.g., Japan or South Korea (Mokhatab 2013). In the producing regions, natural gas is liquefied, i.e., cooled down to -162°C, transported on gas tankers, initially stored at the destination port and, if required, re-vaporized and fed into the regional gas supply network (Mokhatab et al. 2006).

More complicated and not yet established is the small-scale supply of ships with LNG. Here, the cryogenic natural gas must be brought directly to the consumer in cryogenic pressure tanks by truck. This requires an adequate infrastructure and the ships must be equipped for this purpose (Mokhatab 2013). In the field of LNG transportation, special safety requirements must be observed, especially because of the risk of explosion and the extreme danger posed by cryogenic gases to living beings (freezing) (Mokhatab et al. 2006). There are currently 170 ships with LNG propulsion in service, 35 under construction, and 112 ships "LNG ready" (as of 2019, Statista 2021). At the beginning of the development, mainly ferries and supply vessels were built with such propulsion systems, which were always bunkering at fixed locations. Today, however, ships are also in operation that rely on a global supply of LNG (e.g., cruise ships) (SZ 2018). Figure 1 shows a ship-to-ship LNG bunkering process.

DOI: https://doi.org/10.30844/wgab_2021_17

Figure 1: Ship-to-ship LNG bunkering process (photo: © vladsv/Fotolia.com).

To sum up, the use of LNG propulsion in ships has great environmental benefits but also creates challenges in handling the LNG. Due to the safety regulations, the maintenance of the LNG ship systems is very important and requires a high degree of reliability and accuracy. Therefore, the service technicians need a special training, which is oriented to the „IGF“-standard for the loading and unloading of liquefied gas tankers (International Maritime Organization 2017). Apart from the training, digital assistance systems, e.g., based on Augmented Reality (AR) technology, can be used to support the maintenance and service purposes of LNG ship systems. Here, assistance systems offer the possibility of virtually displaying additional information directly on the objects to be serviced. Simultaneously, the interaction with the user can be designed so that the information can be accessed according to the user's needs. In this way, the work process can be facilitated and its performance improved (e.g., avoiding errors or increasing the speed of work). Nowadays, performant end-devices are available, which enable the creation of meaningful AR-based assistance systems but the user-centric development of the user-interfaces is still challenging and decides about the real value.

Consequently, within the addressed use case of handling and transferring LNG on and between ships, reliability, and system safety can be increased due to an optimized service and maintenance process. Thus, the goal of the funded project "LNG Armaturen" was the development and evaluation of a digital assistance system using AR technology with focus on the valves. The development approach was based on the human-centered design process for interactive systems, according to DIN 9241-210. Subsequently, an evaluation was carried out through a user study and an expert review. The developed assistance system based on an Android smartphone enables users to access maintenance instructions and manuals, simplifies spare parts' ordering, and supports the work process step by step through context-sensitive virtualizations. Its evaluation was conducted as a combined quantitative and qualitative user study in the laboratory, which included the processing of a maintenance activity at an exemplary LNG valve (Figure 2). Here, various parameters were recorded, which enabled an evaluation of the developed assistance system. Besides, an expert review with service technicians from the field contributed important findings on the usability of the developed assistance system. Overall, the prototypical assistance system offers promising potentials for reducing workload and improving processes.

Figure 2: A test person is using the developed AR-application while working on the LNG valve during the user study.

In the following, we first put a light on existing work regarding AR assistance systems for service and maintenance, focusing on LNG use cases and AR technology (Section 2). On this basis we continue by a detailed description of our human-centered development approach with several iterations and the created AR assistance system (Section 3). Further, as being of main interest in this research work, we describe the followed approach of evaluating the developed assistance system in terms of a description and an analysis of the conducted usability study and the performed expert review (Section 4). Finally, we finish our paper by a discussion of our results and an outlook on future research work (Section 5).

2. State of Research

2.1 Industrial AR Assistance Systems

AR offers the possibility of adding virtual objects to the real world allowing users to see an enhanced version of reality (Tönnis 2010). According to Azuma (1997), an AR application must have at least the following characteristics: A combination of reality and virtuality, a real-time interaction between users and the application, and a 3D reference of virtual and real objects. AR content can be displayed via data glasses, head-mounted displays (HMD), smartphones or tablet computers (Mayer 2016). The way and quality of integrating virtual representations into reality is described by the term immersion. Immersion is disturbed, for example, by jerky images, high latencies or unrealistic representations (Butz/Krüger 2017).

Quandt et al. (2018) identified potential for AR use in industry primarily in the areas of education and training, assembly support, plant construction, predictive maintenance, quality assurance, product development, production logistics and remote maintenance. Furthermore, indoor navigation and materials management are use cases for AR applications (Fraga-Lamas et al., 2018). In contrast to paper-based information provision, AR can reduce the cognitive workload of users. This is done by virtually overlaying information depending on the context (Gattullo et al., 2020). In this way, complexity can be reduced and errors can be avoided.

When using AR, the user-oriented design of the applications plays an essential role, as this forms the interface between the users and the technology (Mayer 2016). In that way, the usability of AR applications can be increased, which in turn results in higher user acceptance (Dey et al., 2018). Other factors that influence the usability of the AR application are the used hardware (Egger/Masood, 2020), the perceived efficiency of the application from the user's point of view (Syberfeldt et al., 2016) and the cognitive load resulting from the use of the application (Egger/ Masood, 2020).

2.2 AR for Service and Maintenance Support

Several attempts to integrate AR in service and maintenance already exist. Yet, AR is not the only assisting tool in the industrial sector. Collaborative robots are also used and researched (Wolfartsberger 2019). Our interest, however, is in AR service and maintenance systems. In many cases, AR is used as a replacement for paper-based instructions or 2D references (Natakuaithung 2020, Hynes 2019, Chu 2020, Kastner 2020). 2D references lack interactivity and depth, therefore, a 3D view (with AR features) is a more helpful assistance tool (Natakuaithung 2020).

When handling complex constructions in 2D-paper-based representations, users face difficulties in understanding the drawing constructions (Chu 2020). To overcome paper-based manuals, AR-based assistance system with instant interaction can be one solution (Chu 2020, Hynes 2019). An AR instruction is of practical use, since it leads to a lower error rate compared to a paper-based instruction though it can have a higher time consumption (Chu 2020, Kästner et. al. 2020). Other studies could prove a better time efficiency when using an AR approach (Hynes 2019, Kästner et. al. 2020). Another impact can be a lower stress level and success rate (Hynes 2019). For the creation of the AR version, the inefficiency of paper-based instructions should be defined in beforehand (Chu 2020). As tool for implementation, Unity in combination with Vuforia is often used (Chicaiza et al. 2018, Chu 2020, Hynes 2019).

Most related to our concept is the application and study by Chicaiza et al. (2018). An AR smartphone app for training and assistance in the handling of equipment and engineering was developed. In the implementation, physical manuals were transformed to a digital AR format. The AR overlay happens through graphical and text information of the scanned object. In addition, there are audio feedback, explanation videos, and the possibility to save screenshots or images. To prove the usability of their implementation, Chicaiza et al. (2018) conducted a user study using the system usability score (SUS). Their total SUS had the value of 78.43 %, which states high usability, and therefore, they could find their app suitable for training and correctly managing the use of equipment in the industrial field.

The current state of research is comparing a paper-based manual with a digital version using an AR overlay. However, most research does not consider a comparison between different variations of AR and UI. Keeping this in mind, we defined the goal of our study to compare a non-AR variation with an AR-variation of a similar UI and follow a more user-centered design approach.

2.3 Designing an Evaluating User Interfaces for AR assistance systems

Adequate user interface design has a direct impact on its usability for users. Consequently, some guidelines standardize the design of user interfaces (Shneiderman et al. 2018). Besides, step-by-step process models are available to structure the design process to avoid undesirable developments and support the development of a solution, e.g., the human-centered design process for interactive systems according to DIN EN ISO 9241-210 (DIN 9241).

Guidelines for the design of a user interface provide specific instructions, like the layout of images or text (e.g., Google 2020b) to achieve a desired final result. AR design requires to support users being immersed in the AR world and not being disturbed by a flood of information (Stern 2020). Consequently, push or full-screen notifications or a constant display of 2D content for example should be avoided. Possible user inputs should be intuitive and straightforward. The continuity of the AR experience should be in the foreground, and the user's physical interaction should be reduced. If users are already familiar with certain types of interaction (e.g., direct manipulation by dragging), these should be implemented with priority to avoid unnecessary learning efforts (Google 2020a).

User interface design guidelines and principles provide essential guidance on developing a user interface but do not evaluate its usability. For this purpose, different evaluation options are available. They aim to identify weak points of the design and to assess individual user satisfaction. For the evaluation of interactive systems, evaluation methods by experts or by users of the system are most common (Dix 2004). Usually, different expert- and user-centered evaluation methods are combined (Billinghurst 2014).

A user-centered evaluation reduces the risk of developing systems that do not meet users' needs. This way, prototypes can both be tested at an early stage, and the fulfillment of user requirements can be promoted. Also, qualitative feedback can support problem identification and enable immediate improvement or consideration for a later system version (Heinecke 2012).

A standard method for evaluating interactive systems are experimental evaluation studies (Jacko 2012). They can be used to show whether there are causal relations between the design of a human-machine system and effects on the humans involved, the system, or the overall system performance. Therefore, in an experimental study, one or more variables are modified in order to induce observable effects (Jacko 2012, Wickens 2014). The gain of knowledge is mainly achieved through social scientific data acquisition techniques such as interviews or questionnaires (Badke-Schaub 2012) and can be used to facilitate design decisions (Stern 2019).

In production and logistics scenarios, we usually focus on the system's usability to improve the interaction between users and technology. Therefore, questionnaires for assessing the perceived usability of an interactive system such as the System Usability Scale (Brooke 1996) can be used. The goal of a subsequent statistical evaluation of the experiments is to answer whether the selected independent variables (factors) influence the dependent variables.

3. Approach and Solution

According to the challenges presented at the beginning of Section 1 dealing with the handling of LNG, an AR solution was developed that can be used for maintenance and service purposes of LNG valves. In this context, AR offers the possibility of virtually displaying additional information directly on the valves to be maintained. This way, the user is able to call up information as needed. Thus, we aim to improve the performance of the work process (e.g., number of errors, work perception) using AR support.

We developed the AR solution according to the needs of the technicians. Here, the process for designing interactive systems according to DIN 9241-210 was used as a guideline. Its steps, such as understanding the context of use, specifying the requirements for use, developing design solutions, and evaluating them from the user's perspective, were carried out.

Based on user stories of the employees, we initially determined the requirements in order to increase the added value of the assistance system. The result is a concept for AR-based support, which provides assistance for component replacement in the context of regular maintenance or critical malfunctions. For this purpose, we focused on the activities "retightening the valve" and "replacing the gasket". These activities are often carried out onboard the ships on which the valves are used. Consequently, it is often impossible to send a service technician, and the AR solution must be suitable for different user groups and usable without additional hardware. Therefore, an Android smartphone solution is used by providing a context-sensitive AR-based work support application.

The application was developed using Vuforia software and Unity game engine. We provided assistance through visualizations in the form of displaying the process steps that need to be carried out. The identification of the components of the LNG fitting is image-based using markers. The markers are collected in an image library, with each marker having a link to one certain valve. This provides an clear identification between them and additional markers can be added easily. In the first step, features of the markers are identified, such as edges and corners. To search for the marker in the image stream, geometric patterns that could correspond to the marker are searched and compared with those of the marker being searched for. If there is a match, size and deformation of the pattern can be used to infer the distance and viewing direction to the marker. Due to its widespread use in the AR segment, Vuforia was chosen as the framework for development (for more details on the design process, see Section 3.2). Early in the design process, mock-ups of the planned application were created and assessed, and qualitatively evaluated in collaboration with the users of the application. Improvements resulting from this were directly incorporated into the further design process (Section 3.1).

After the development of the application, an evaluation study consisting of a user test in the laboratory and an expert review in practice was conducted (Section 4).

3.1 Development of Mock-Ups

Before the actual assistance system was implemented, we developed several interactive mock-ups and iterated them for the design and its functionality. In the following, the development of the mock-up is described in detail. The tool Adobe XD was used to specify the UI based on the user requirements since it allows to share the developed UI with others.

Another important point was the consideration of valve detection. We came up with two possibilities. The first was of a simple image/tag recognition by adding tags next to the valves. The second was the valve serving as a model for detecting itself (object recognition). Here, tag detection was found to be the better solution, due to two reasons. One consideration was the problem with the detection of the valve itself, as there are too many very similar models, with an almost impossible differentiation between them. The other consideration was its installation aboard a ship, where most valves and armatures are covered due to isolation, which also makes object recognition almost impossible.

A paper-based instruction served as the model for the creation of the mock-up. The instruction consisted of information like a sectional drawing, information about the usage of the valve (e.g., the temperature ranges the valve can be used in) and step-by-step instructions for several service and maintenance tasks. For the processes of replacing and tightening we used the already existing picture instructions divided into several mounting steps. Figure 3 shows the instruction for the first mounting step for replacing the gasket.

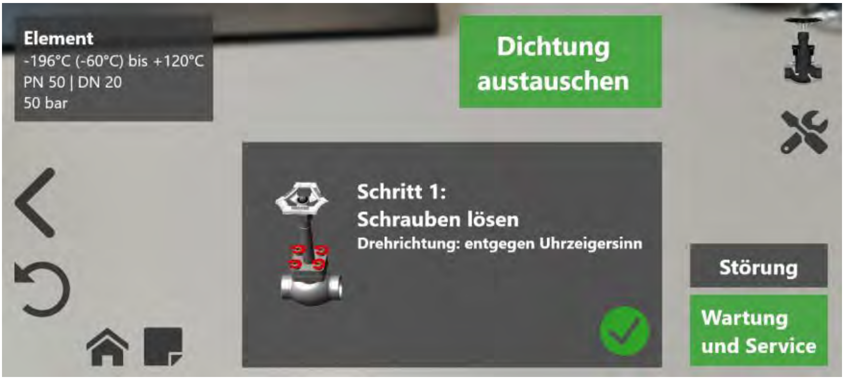

Figure 3: Screenshot from the mock-up with the first assembly step of the task "replacing the gasket" as an example. It displays information on the detected valve (left), on the current step of the task (center), and on the navigation within the app (right).

With relation to the paper manual, we designed the interface for the application. After the valve was detected, we thought about the possibility to define the casing of the object, which can cause a change in the torque of some screws. This step is followed by the main menu. Here and for all following pages, we added a back, rescan, notes, valve, and home button. When coming to the actual maintenance and service tasks, we thought about two ways leading to the instruction steps. On one hand, we designed a navigation when only the problem is known, but not its remedy. On the other hand, we offer a navigation directly to the remedy. It leads the user directly to the instructions, in our case "tighten" and "replace the gasket". After the remedy was chosen, the instruction steps are displayed with internal navigation of going forward and backward only affecting the maintenance steps. In addition, we decided on an extra button in the maintenance steps for the needed tools to complete the task.

By linking the created pages within Adobe XD, the mock-up became interactive with the buttons leading to the page of its purpose. One example of navigation is shown in Figure 4.

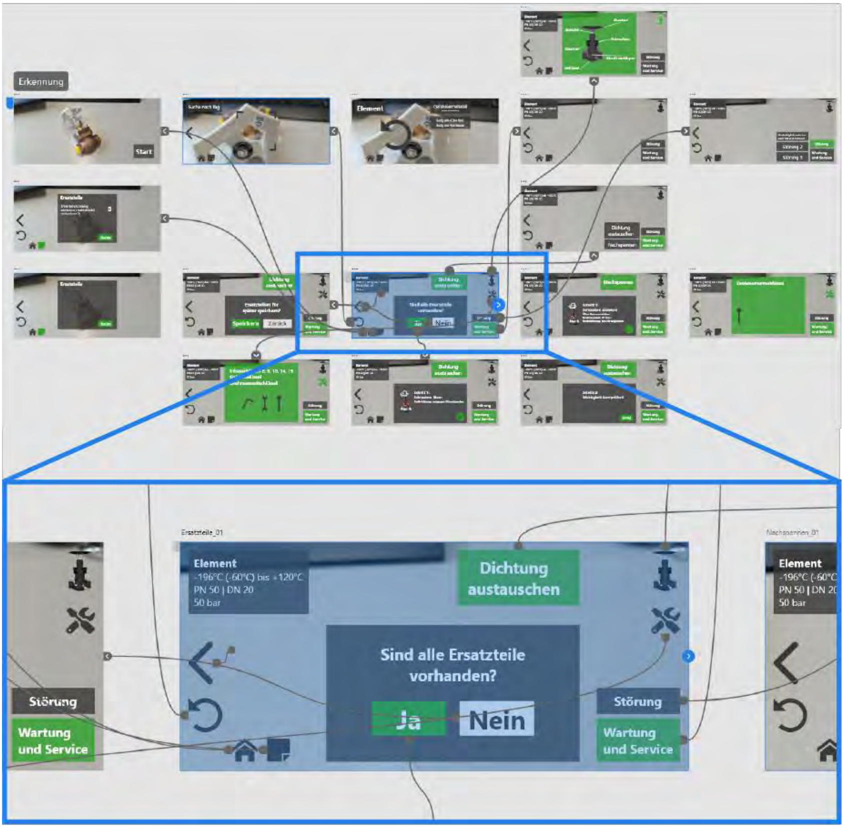

Figure 4: Example of the interactions between different pages (curved grey lines) in the mock-up when interacting with a button.

A finished first interactive mock-up was discussed with two expert users. The main discussion points were the position of the tag, a need for a direct help button, the side of main menu buttons, an overview about spare parts, the torque value, and another maintenance step.

The tag was thought to fit best on the handwheel of a valve, as it would be too small and hard to replace. However, a final solution for the placement was not found. Whereas the main menu could be arranged anew, by switching the side, following the reading direction. A direct help button was also added, for a better communication to the service as well as the possibility to save and send an order request of spare parts.

An important point for replacing the gasket maintenance steps, is to inform the user about depressurizing and rendering inert the installation as mandatory, before disassembling the valve. Additionally, a button for the required tools was found to be useful. Bearing all this feedback in mind, we continued to the implementation of the application. Now, the mock-up served as a guideline in the final development phase.

3.2 Development of the AR-Assistance System

The application was finally implemented in Unity. According to the feedback for the mock-ups, the menu was switched to the left side and a direct help button with links to the partner website, a service mail address, a phone number as well as the pre-step (step 0) were considered.

The AR function was added with the help of the add-on Vuforia. Vuforia provided a program in which 3D models can be imported and used to train a machine learning algorithm for object recogition. This model can be imported into Unity and used together with the Vuforia add-on. Since the object recognition happens directly at the valve, the UI had to be re-thought. Now, the screen should have more space for the camera and the information had to be placed in a smaller text field. With several layout attempts, the right proportions were found. Figure 5 shows an example for the AR interaction with an example step (remove top part and gasket).

Figure 5: Screenshot of the AR version of the application with the third step an example of the digital instruction.

After all previously defined functions and navigations were implemented, we considered a second version of the application with less AR features and tag detection. Therefore, we duplicated the Unity project and replaced the object recognition with image recognition. For this feature, we added the add-ons AR Foundation and AR Core. The AR Foundation provides methods for image recognition. Only the image, which should be scanned, had to be added to a predefined image library. Also, we had to define what happens after the image was successfully scanned. In addition, AR Core was required to build the application for Android, otherwise, the AR functions cannot be used. As the simple instruction images have no depth, we decided to use the 3D model of the valve and added some explaining animations, showing what has to be done. An example of the implementation is shown in Figure 6.

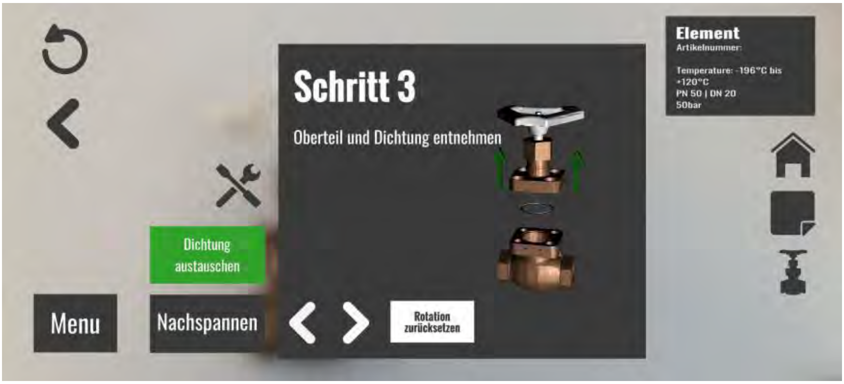

Figure 6: Screenshot from the normal version of the application with the third step as an example of the digital instruction.

For both applications, we added a script to track the time (for each step, step time in total and overall application usage time), taps (for each step, step taps in total, and taps for the entire usage of the application), and button presses for additional comparison factors for the evaluation of both versions.

4. Evaluation

After completing the development phase of the AR application and the altered version without using AR technology, we carried out a comprehensive evaluation. As described in Section 2, we followed an approach that combines a user study in the laboratory with an expert review (Billinghurst 2014). The underlying idea was that test users perform a specific maintenance and service task on a real LNG valve (replacement of a gasket). The test users were supported either by means of the AR app or the non-AR app. In some cases, the test users were experts who work professionally in maintenance and servicing of LNG valves. In these cases, we focused on a qualitative evaluation of the usability of the AR application in practice. During and after the execution of the task, we were able to collect information on work performance and work perception by tracking qualitative parameters and by means of a questionnaire. For this purpose, the System Usability Scale (SUS)

(Brooke 1996) and the NASA-TLX methodology (Xiao 2005) were used in the questionnaire. A combination of these two commonly used techniques (Sauro 2011, Xiao 2015) was used in our study in order to both address the usability of the applications and the cognitive and physical workload which is caused by its usage. In this section, we will go into detail about the setup and implementation of the user study and the expert review, as well as describe and evaluate the results acquired.

4.1 User Study – Laboratory Test

4.1.1 Setup

The setup of the laboratory test consisted of an assembly workstation, the LNG valve, the necessary tools, a replacement gasket and the smartphone with the application for support (Figure 7). The test sequence followed a consistent procedure in each case: First, the test administrators gave a short introduction; during the entire experiment, the test users were allowed to ask questions. Before starting the task, the test users were instructed about the specific task (replacement of the gasket). After completing the task, all test users filled out the questionnaire and were then able to give further comments on the application and the experiment in a short interview. In beforehand of the actual user study, a test run was performed.

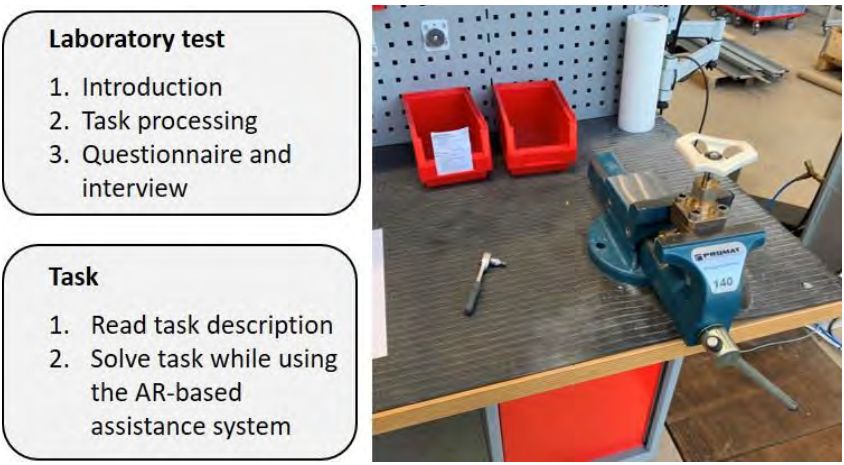

Figure 7: The setup for the laboratory user study.

We could acquire in total ten participants. Unfortunately, one participant could not speak German, which lead to a much longer finishing time and comprehension problems. For another participant, the log was not recorded correctly. Due to this, we decided not to consider them in our evaluation and results. All other participants have been male, are employed, and are between 28 and 51 years old (mean=34.6). They stated that no one has prior experience in professional maintenance, whereas almost everyone, except for one participant, has prior experience with AR, with no especially familiarity with AR (mean=2.429, with a rating between 0 and 5).

The experimental design was that half of the test users would use the application in the AR version and the other half in the non-AR version. The allocation was randomized. As already shown in Section 3, the two applications differ in whether they use AR technology or 3D animations to illustrate the work steps. This procedure allowed us to compare the effects on work performance and work perception triggered by the AR application with those of a similar application. Thus, distortions of the results based on confounding variables (Jacko 2012), such as hardware used when comparing a paper version with an AR application, can be avoided.

The questionnaire was divided into four sections. The first section contained general demographic questions. In the second part, we asked for the system usability, using the established system usability scale (SUS) questions and the corresponding 5-point Likert scale. The SUS contains questions about the usage of the application, its complexity, and its functionality. The third section was about the task load divided into mental demand, physical demand, temporal demand, performance, effort, and frustration, following the NASA-TLX. To not confuse the participants with different point scales, we decided to choose a 5-point scale, as we used for the SUS. In the last part, we asked about the general impression of the experiment and the application with a last free to fill in a text field.

4.1.2 Results

The results can be divided into the system usability, task load, time and tap measurements, and the interview, which are described in the following.

As Figure 8 shows, the AR application has slightly lower usability. The normal application has a total mean scale of 83.75 % (SD = 4,1), while the AR version has a total mean scale of 83,125 % (SD = 9,6) which is a little below the total average of 83,4375 % (SD = 7,39). The worst achievable score is 25% and the highest is 100%.

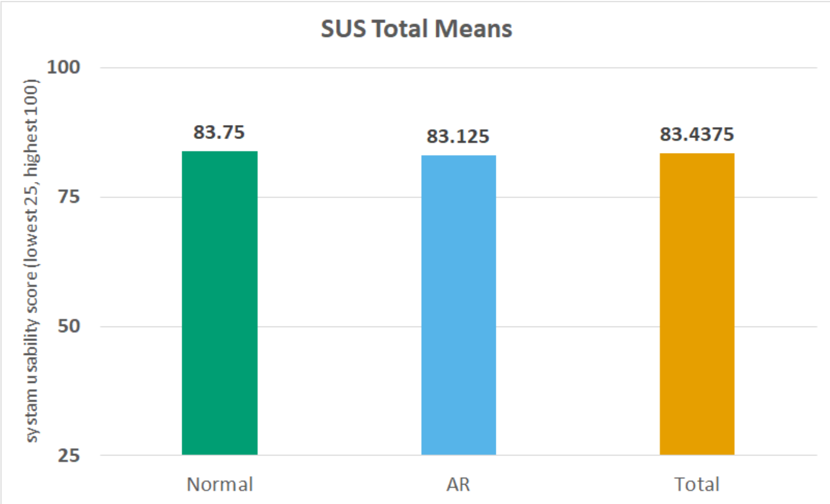

Figure 8: The system usability score means for both versions and the total average.

With a mean scale of 11.25 (SD = 1.79) points, the participants stated, that they had a little higher task load with the AR application (mean = 10.78, SD = 1.48) and the total average (mean = 11, SD = 1.66). The lowest task load possible is 6 points and the highest is 30 points, which can be seen in Figure 9.

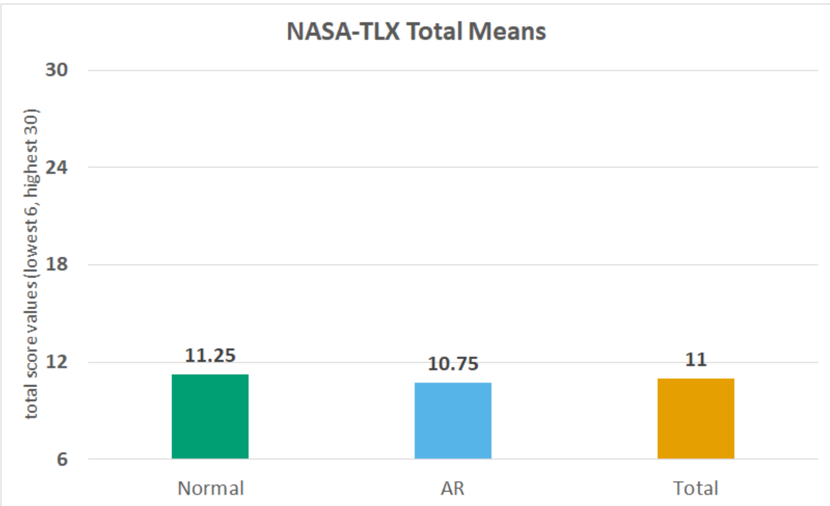

Figure 9: The NASA-TLX mean scores for both versions and the total average.

Concerning the log files, the results show that participants, using the AR application, needed almost three minutes more than compared to the normal version. With the normal version, the participants needed 04:20 minutes (SD = 00:01) and with the AR version, the participants needed 07:30 minutes (SD = 00:05). The time differences are shown in Figure 10.

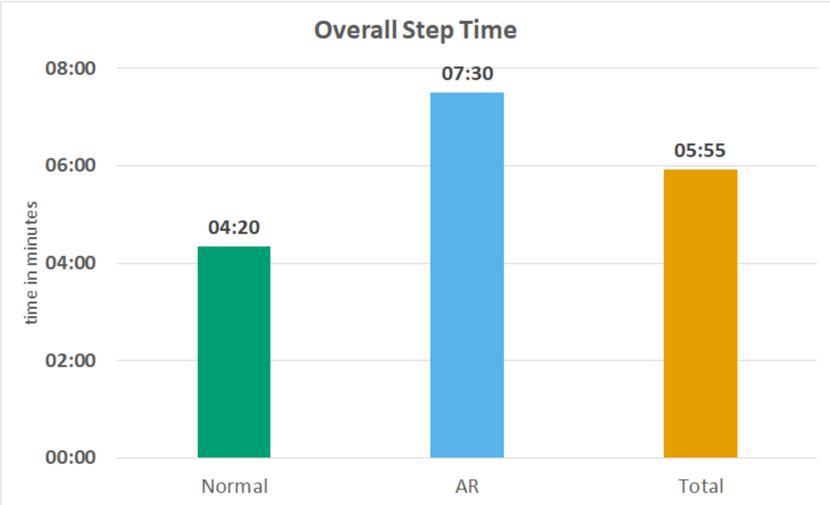

Figure 10: The means of the time needed to complete all instruction steps for both versions and the total average.

Furthermore, the participants also tapped more often on the phone screen, using the AR application, than using the normal application. With a total mean of 23 taps in AR (SD = 5.34) and 12.75 taps using the normal version (SD = 0.83), the difference is more than 10 taps, which is shown in Figure 11.

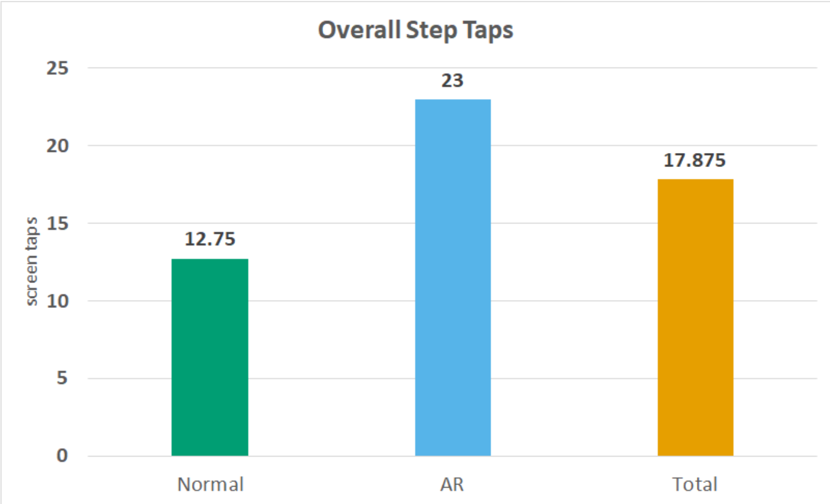

Figure 11: The mean of the taps needed to complete all instruction steps for both versions and the total average.

Besides the time and tap measurements, the logs reveal, that one participant toggled between step 1 to step 0 for five times, before continuing to step 2. Another participant first opened the steps to tighten the screws. The same participants also toggled two times between step 1 and step 2, before continuing with step 3.

During the study, we observed the participants whether all steps were followed correctly. With these observations we could figure out three types of errors. The first type was not replacing the gasket correctly. Only one participant did not replace the gasket, but adding the new one on top. The second type of error was not following the instruction at step 0 to loose the handwheel, which was not followed by six participants. The last error is not tightening the screws crosswise, not followed also by six participants. When comparing both application versions, the participants using AR (mean = 1, SD = 0.71) made half an error less than using the normal version (mean = 1.5, SD = 0.5).

After the experiment, we gave the participants the possibility to tell us about their impression of the application. The statements of the interview, combined with our observations during the task are summarized in the following.

Overall, both applications were well received, thought to be useful, especially for inexperienced people, and self-explaining. The UI was found to be good. However, some participants stated that some instruction steps are trivial and therefore, should be combined with others.

The task itself was mostly well apprehended, but some wished for an explanation video as an introduction. Only a few participants were confused when coming to the spare parts question. They could either not find the spare gasket or were expecting more than one gummy gasket, reasoned by too much information in spare part dialogue. Also, for one participant, the ending of the experiment was a little unclear. In general, that the task was found to be too simple, especially for the AR version.

The participants used the phone differently. Three participants, all using the normal version, were holding the phone in their hands only for scanning the tag and afterward placing it beneath the jaw vise. Three participants, one of them using the normal version, operated similarly but picked up the phone from time to time. The other two participants (AR) hold the phone almost permanently in their hands.

During the experiment, some participants struggled with the valve itself. In some cases, the top part was hard to remove, in others, the screws were stuck to the casing and were hard to loosen. Also, in some cases, the gasket got stuck at the top part of the casing.

The participants, using the normal application, stated that they were confused about the tag and wished for a QR code. In addition, two participants wanted different feedback after the tag was detected and wanted the tag to stay detected when using the back buttons until reaching the main menu.

On the other side, the participants using the AR version were looking for a tag instead of scanning the object itself for detection. Yet, the AR features were well received, though not all animations were found to be useful. Furthermore, when the top part was dismounted, the participants tried to scan the top part and for this, the animation was rotated for 90°. The participants also wished for a hint, when AR is really necessary, for knowing when to pick up the phone or a mix of AR and instruction videos were liked.

Other improvements were proposed by the participants, containing a highlight or confirmation (checklist) of the most important steps and lighter animations, a voice control, a bigger information field, a preview of the next step, documentation tools (take a picture, adding own text to the notes) and an English version.

Lastly, some participants mentioned, they have tightened the screws crosswise, due to previous knowledge and one participant explained that the orientation of the valve's top part was not clear when remounting it.

4.2 User Study - Expert Review

In contrast to the user study in the laboratory, we modified the procedure for the expert review due to the professional background of the two participants. Here, we chose not to provide an explicit task, but rather to support a free testing of the app. Participants were first asked to familiarize themselves with the app and then perform the same task as in the lab test (replacing the gasket). After completion of the task, the questionnaire was used to evaluate the usability of the application as well, and the impressions of the test users were queried in a subsequent interview. Due to the different focus of the study, only the AR version of the application was used in the expert review.

During the review, we could figure out some problems regarding the application. Like in the user study, the navigation was a bit unclear at the beginning, as one expert tried to press the valve-button in order to open the disturbances. Besides, we had to point one of the experts to make use of the AR functions, which then were well received. After the troubles in the beginning were overcome, the application was used as intended, though from time to time the animation froze.

In the interview, the experts could give more information about the assembly steps. The experts mentioned there should be more emphasis on the step for loosening the handwheel. Furthermore, it was stated that the replacement or greasing of the screws with a premium stell valve should be added and highlighted and before reassembling the top part of the valve, the sealing surface should be checked for dirt and damages.

Overall, the application was well received. Especially for the maintenance on board, the experts stated a high potential of the application. It was thought to improve the service with professional instructions always available on every smartphone. However, it was also thought about the bad conditions on board (light, isolation), suggesting a combination of AR and video tutorials or even the usage of AR glasses.

5 Discussion

With both applications having a usability of more than 80 %, each version is of a high usability. This result is based on eight, non-specialist participants, which need to be taken into consideration here. Nonetheless, the participants with the normal application were faster in solving the task, but have done more mistakes and had a slightly higher task load. With relation to the use case and the sensitive safety regulations this is an important aspect. On the one hand, the time difference was caused by two participants (AR), who swapped between some steps several times. But, when calculating anew the completion times, leaving out the for and back taps, the AR version still is in average more than two minutes (mean = 06:49 instead of 07:30) slower than the normal version (mean = 04:20). On the other hand, when using the AR version, the participants have to pick up the phone more often and re-scan the objects. This will also cause a rise in time. A possible solution for this is using a tripod, so the phone stays in place and the user must not always pick up the phone and rescan the object, so the user has the hands free for the task. Alternatively, an AR-HMD can be used.

The second proposal for the task completion can also explain the difference in the phone usage. As the participants always have to pick up the phone to rescan the object for showing the animations, when using the AR version. In contrast, in the normal version, the participants could access the animation at all time and just had to tap forward or backward. With this background, the normal application was more likely for hands-free tasks.

A solution for the tracking problems in AR, when the top part of the valve is dismounted can be training an own model for the single parts. At the moment, only the entire valve exists as a model reference. Together with the predefined tracking settings, it is limited and the animation might appear rotated, as the last position of the object was saved in the memory. Another option is the possibility to overlay the AR version with instruction videos or animations or to combine the previous step with the one when the gasket is replaced, like the participants wished for.

In the expert review, the experts mentioned that the animation froze a few times, which might be due to the different phone, which was used. The object recognition and its animation are complex and as the phone used in the user study was a high-end model, the complexity was not of a problem, but on other phones, with a different processor, the performance can drop. In order to the impossibility of using the normal app, a different kind of base of an image recognition, which does not require AR Core, can be used. Then it should also be possible to install the applications on both, Android and Apple smartphones.

Finally, the task itself should be considered. Most participants stated it to be too simple, which was due to the paper-based instructions we received from the manufacturing company of the valve. At the expert review, the experts stated that the functionality would also fit for harder tasks, but for the usage on ships and several different valves, also the task we chose, was found to be reasonable. Considering the learning curve, simple task can be usefully supported with AR overlay instructions, but with some experience, a simpler instruction would probably do it. On the contrast, when the task itself is more complex, AR might reveal its full potential since it was found to be very beneficial at lowering the mental workload at complex and varying tasks, i.e. we expect a more significant difference in error rates here.

6. Summary and Conclusion

6.1 Summary

In this paper, we proposed an assistance system using AR and image recognition to support the maintenance on board of an LNG driven vessel. In order to transfer paper-based instructions for service and maintenance into an AR Assistance System, we first did a requirements analysis and translated the results into a mock-up. After professional feedback, where we received improvement suggestions for the application, we developed two different versions of the application, an AR version and a more basic approach with image recognition (tag). For their implementation, the mock-up served as model.

With the two versions of the application, we conducted a between-subjects user study. Its main goal was to compare both versions to find out which is performing better in terms of usability, task load, task completion and the error rate. Both versions showed a high usability, with the normal version having a lower task completion time, but the AR version having a lower task load and a lower error rate. Keeping in mind the difficult surrounding conditions on a ship, with mostly isolated valves, other components, and difficult lighting conditions, we conclude that a mixture of both versions and the possibility to switch off AR would fit the purpose of this application best.

6.2 Future Work

As future research work, we consider several starting points and actions. First, some changes and improvements of the AR-based assistance systems could be implemented, which are both hardware- and software-related. Here, an AR-HMD (head mounted device, e.g., Microsoft HoloLens 2) could be used instead of an AR-Handheld to improve the systems ergonomics (hands-free use). Besides, we expect a particular UI-design focusing on AR to increase the usability and performance of an AR-based assistance system. Further, as highlighted by the study participants, a mixed version of the AR-application and the normal application could combine the advantages of both systems. Here, e.g., allowing users to toggle between AR-virtualizations at complex process steps and a basic, non-AR-process guide could be helpful.

With regard to the evaluation of the AR assistance system, further user studies would be useful. Here, a larger number of test users as well as a better fit of the test users to the intended system users (e.g., with regard to prior knowledge, technology affinity) would be helpful to increase the validity of the study results. Furthermore, other, more complex tasks or components could increase the generalizability of the results.

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Assistance systems in learning factories

A systematizing overview and case studies

Christof Thim, Gergana Vladova, Sander Lass

1. Introduction

In performing production tasks and processes, employees require both theoretical and practical knowledge (Lassen, McKelvey & Ljungberg, 2018). Especially in adaptive production systems called for in Industry 4.0, learning is not merely instructional but always has to encompass a degree of immersion to impart the complex interplay of task and technology (Schuster et al, 2016). For this reason, learning on- and near-the-job gain importance. In order not to interrupt real production processes and to avoid faulty production, simulated working environments in learning factories can be used for learning purposes. This paper discusses assistance systems that support learning in production processes. The goal of the paper is to structure the possibilities of assistance systems use regarding different learning goals.

Learning systems can be used at different stages within a production process. Accordingly, they are also deployed in various stages of the learning process (Wandke, 2005). With the specificity of learning of production technology and processes, assistance systems can provide awareness, information, direction, and feedback. Guiding the attention of the learner and providing information within a real-life scenario is seen as beneficial and instructive. Yet, learning objectives differ and assistance systems need to be selected and embedded in a learning scenario adequately.

To address this selection and integration problem, we first present a taxonomy for assistance systems that encompasses different stages in the production process (section 2). We furthermore extend this taxonomy with learning theories and objectives to classify assistance system use (section 3). The resulting extended taxonomy of assistant system use in learning factories describes single and integrated usage scenarios (section 4). A case-study approach (section 5) is used to demonstrate this taxonomy. Through three exemplary cases, different areas of the taxonomy are presented. The benefits and obstacles of each scenario are described (section 6).

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2. Taxonomy of assistance systems

Assistance systems are in use in different domains from their application in everyday life like driving cars and guiding the operation of information systems to industrial usage e.g., in operating machinery, maintaining facilities, and monitoring production processes. The main purpose of assistance systems is to extend the capabilities of human operators in different aspects to achieve an individual or organizational goal faster, with fewer errors, or more secure. Assistance systems thereby enhance perceptual (visual, tactile, hearing), decision-making (information-presentation, pre-processing), and activity (range extension, strength amplification) capabilities (Mark, Rauch & Matt, 2021).

2.1. Classification by interaction stage

To structure types of assistance systems, Wandke (2005) proposes a six-step taxonomy that is oriented towards a flow of activities that can be assisted. Starting from motivation and activation through perception, information integration, decision making, and activity execution to feedback, assistance systems can provide different extensions to human capabilities. Within each activity, there are different ways in which assistance systems are involved.

In the *motivation and activation* stage, assistance systems nudge humans to execute desired activities through activation, coaching, and orientation or omit undesired activities through warnings (Dostert & Müller, 2020). Typical systems can be found in wearables, which keep the user updated about their activity goals or which monitor health parameters.

At the *perception* stage, assistance systems display and present environmental information, they guide the attention of the user (Bottani & Vignali, 2019). Furthermore, they can be used to amplify or filter environmental signals to focus attention. They thereby extend the human ability to extract information from the environment. Examples are driving assistance systems and haptic feedback systems.

While systems in the perception stage interface between the user and the environment, the next stage enriches input signals with *additional information* and contextualizes the inputs (Alm & Hadlak, 2015). Typical applications label signals from the environment, interpret situations, or even explain the environment or usage context to the user. Examples for these applications can be found in augmented reality supplements, where status data about machinery is displayed for the worker.

Systems in the fourth stage go beyond informing and recontextualizing situations. Active decision support or even autonomous *decision-making* characterizes these systems (Nelles, et al, 2016). They either supply, filter, or propose decisions. At this stage, humans select the final decisions, yet the scope of these systems already goes beyond this capability.

Active decision-making by delegation, take-over, or even silent execution can be found here. The decision-making capabilities of assistance systems are found in autonomous factory settings or in risk-prone operating environments, where erroneous and dangerous human decisions are blocked or questioned by the system.

Besides decision-making, assistance systems are involved in the *action execution*. While human muscular power and coordination are limited, systems can amplify power e.g., through exoskeletons or limit and dose human power in sensitive areas. Assistance systems in this area are closely associated with human movements and need to capture and translate (Mark, Rauch & Matt, 2021).

The sixth stage of the taxonomy is related to the *feedback* assistance systems can provide, when actions are executed. This can be a simple report about the state in which the technology is, but it can also encompass a critical retrospective of human actions (Yang & Plewe, 2016).

2.2. Classification by interaction type

Aside from the different stages of human support, assistance systems can *interact* with their context differently (Wandke, 2005). Fixed assistance systems are not context-aware and just guide the operator in a predefined way. Customizable assistance systems allow are adjusted during design for the specific needs of the user group. Adaptable systems can be adjusted by the users to their specific need through parameterization. The assistance system is thereby interactive towards the user. In comparison, adaptive systems modify themselves regarding their environment and user behavior. They thereby need the capabilities to reason about their perceptions and actions. Adaptive systems often go along with AI capabilities. If the usage environment is uncertain and less predictable, a higher degree of adaptiveness is needed, while an anticipatable environment with little degrees of freedom allows fixed assistance systems.

The degree of interaction with the environment is also closely related to the type of *initiative* an assistance system provides (Wandke, 2005). Passive systems need to be triggered by the human to provide help. Active systems are engaging the user by perceiving the assistance situation themselves. In all presented stages, passive and active systems can be used. However, in warning, orientation, and activation systems they need to be active, as they are the guiding factor in the interaction between user and environment.

2.3. Classification by presentation type

The third way of classification is the type, in which the support is presented. Different media like texts, graphics, pictures, animations, videos, and sounds can be used to provide visual and audible assistance. Recently the augmentation of media and environment has become increasingly attractive. In general, the following *presentation modes* can be distinguished. *Mono-medial presentations* focus only on one output media e.g., by only presenting textual outputs as hints. *Multi-media presentations* on the other hand combine more than one output media. Especially when warning or hinting is required, a combination of visual, audible, and tactile channels can interrupt the user with more certainty. The third way of presenting the assistance is *implicit*. This mode of presentation is found when the assistance system is directing acting in the environment or is amplifying the actions of the user. Instead of receiving explicit hints, the user only experiences the effects of the assistance system e.g., if machinery is stopped due to faulty operation.

In the factory environment, assistance systems are often used in combination. As head-mounted displays guide workers through their tasks, machine interfaces provide feedback about the actions and direct the attention of the worker. Robotics or exoskeletons provide additional power. Often, multiple systems are coupled e.g., when the worker is interacting with a robot wearing a head-mounted display, which provides information about the robot's current tasks.

It is without saying, that assistance systems are ubiquitous in modern factories. However, it is unclear which impact these systems have on learning activities in a manufacturing setting. Taking the perspective from different learning theories and applying those to learning factories, guides the analysis.

3. Learning Theories and Learning Factories

The increasing velocity of changes in a factory setting requires constant adaption of the workers towards new technology. While traditional learning arrangements such as seminars, training-on-the-job, or workshops address the conveyance of factual knowledge, interactive concepts such as learning factories help to build up action knowledge.

3.1. Learning Factories

Learning factories enable workplace-oriented learning in technology-oriented learning environments in which production processes of real companies are simulated in detail but in an abstract manner (Gronau, Ullrich, & Teichmann, 2017).
Extensions with Industry 4.0 elements such as mobile Internet of Thing technologies (IoT technologies) demonstrate their impact and train their use in an individual context. The proximity to real processes and the resulting possibility of immediate contextualization of new knowledge content reduces the risk of any (knowledge) transfer problems. Theoretical knowledge and its practical application are linked by overcoming the difference between theory and practice. Learners from the manufacturing industry can thus independently develop competencies close to their own work process without being subject to the restrictions and constraints of the original system.

Although there is no exact definition of the term "learning factory", the use of model systems is a general characteristic feature (Grodotzki, Ortelt, & Tekkaya, 2018; Wagner, Al Geddawy, El Maraghy, & Müller, 2012). More specifically it contains two distinct aspects: the technical representation of an original factory system (model factory) and a didactic concept (learning context).

As a *model factory*, learning factories are thus technical model systems exist that represent original systems (e.g., production lines) and production processes. The elements of a model factory are combined into manufacturing sequences that represent the work process with simplified instances of the individual operations a model of the real product. In the form of workstations, actors (e.g., workers) can interact with the plant in different ways within processes and scenarios. The underlying model factory comprehensibly forms a terminating feature of the performance of a learning factory.

Various forms of interaction between process actors (human to human, human to machine, machine to machine) can be realized. The model character eliminates the risk and safety to humans or machinery in the original plant. Regarding the objective of training and learning, the general requirement of reproduction of the original is joined in particular by the requirement to allow learners to act in and explore a realistic environment. Learning factories, therefore, need to offer a sufficiently high level of immersion. Assistance systems can provide additional immersion in two aspects: as part of the represented real factory system (assistance system as an object of learning) or as a device that guides the learning process (assistance systems as a means of learning). In this paper, we consider the latter. Likewise, the usage of assistance systems needs to be assessed in the context of learning theories.

The second characterizing aspect of a learning factory is systematic knowledge transfer. This requires the use of a basic didactic fundament on which the implementation and application of the model factory rests. Hence, a model factory requires a suitable *didactic concept* to be able to act efficiently as a learning factory. The didactic concept is based on a selected learning theory. Regarding the learning objective, it defines the core didactic elements and levels from which the design of the learning scenarios is deduced.

3.2. Learning Theories

Several factors influence how adults learn, e.g., their life-centered, task-centered, or problem-centered, experiential, discovery-based orientation to learning (Kaufman, 2003; Knowles, 1970; Moon, 2013; Spencer & Jordan, 1999). Learning theories represent different assumptions about the processes of knowledge transfer that can be put into action, when planning learning scenarios and developing learning modules (Gardner & Thielen, 2015, p. 43). We will give an overview of the most widely used: behaviorism, cognitivism, constructivism, experiential learning, connetivism as well as multi-model learning.

Behaviorism (Skinner, 1965) sees knowledge as an external object that is not bound to the learner. Knowledge is conceptualized as showing the desired behavior, even without understanding the context (Gredler, 2005). Learning is conceptualized according to the stimulus-response scheme; thus, it aims at the repetition and routinization of learning material and tasks to initiate behavioral change. Typical learning modules are question-answer sequences (e.g., vocabulary training) and repetition of simple factual knowledge. No problem-solving skills and individual learning paths are not supported.

Cognitivism (Piaget, 1954) is a group of learning theories that relates learning to the cognitive operations of the learner. Knowledge is an object, which is transferred through the learner's internal cognitive processes. Learning is therefore seen as an individual information processing within the learning environment. The individual cognitive scheme can either be adapted to the environment (accommodation) or the environment can be changed through individual actions (assimilation). These approaches aim at exploratory learning to transfer processual knowledge (Erpenbeck & Sauter, 2013, p. 38).

Constructivism (Piaget, 1954) is one group of theories that are concerned with learning through exploration and experimentation. Learning is seen as the ability to identify and solve problems independently. Knowledge is therefore not transferred but constructed internally by the individual. New knowledge is linked with existing knowledge (Gardner & Thielen, 2015, pp. 54-55). The construction process relies on active interaction with the environment to establish cause-effect-relations. The construction process is furthermore a social process, in which the interaction with the teacher and other learners is constituting the learning results. The process of construction can again be guided by individual and situation-dependent learning paths (Erpenbeck & Sauter, 2013, p. 39). In contrast to behaviorism, constructivists stress that learning is a fuzzy process, which can in part be guided but is foremost dependent on the learner's ability to explore and experiment. Learning factories with their representation of the real factory are ideal to apply constructivist approaches as learning should take place at the workplace or in the environment where the knowledge is applied. Learners can communicate, collaborate, and experiment in a close to real scenario and environment. Learning success depends on the most realistic possible design of conditions and tasks in the laboratory. Also, guidance in exploring is provided through different learning paths. Intelligent tutorial systems are used to continuously diagnosing the learning process and instruct the learner accordingly.

One specific constructivist theory is the *experiential learning theory* (D. A. Kolb, 1984). Learning is thereby a process of knowledge creation through experience. Experiential Learning Theory aims at providing "a holistic model of a learning process and a multilinear model of adult development" (D. A. Kolb, Boyatzis, & Mainemelis, 2001). In the context of changing technologies and automation, these learning settings have been recognized by many companies as suitable for the acquisition of corresponding competencies (Kluge, 2007). According to (A. Y. Kolb

& Kolb, 2005), experimental learning is built on the following main propositions: Learning should be seen as a holistic process of adaptation to the world and results from synergetic transactions between the person and the environment. It is best conceived not in terms of outcomes but much more a process of creating knowledge. The main advantages of experiential learning are associated with the high learner activity and with the possibility to create an appropriate learning environment especially for vocational trainees (Kluge, 2007). Kolb (1984) defines four stages of learning are proposed, into which different activities can be subsumed:

- The concrete experience of a person carrying out a particular action;
- observation and reflection of the effect of the action in a particular situation;
- formation of abstract concepts and understanding the general principle under which the particular instance falls;
- testing of the concepts in new situations.

This learning theory is closely related to the ideas represented in learning factories. The model factory aspect eases experimentation and testing of assumptions without risking safety or disrupting operations. This is especially true when learners are confronted with new technologies. Didactical means as instructional material, well-designed tasks, and scenarios, as well as personal and digital interaction, can help in reflection and abstraction. Assistance systems can be used to enrich the experience, guide through the scenario, and present instructional material.

Connectivism (Siemens, 2005) focuses on interaction. Knowledge is seen as socially enacted and present in networks between learners, information, and its environment. Learning is thus not knowing how to solve problems but locating persons or entities who can and reflecting their ability to do so (Erpenbeck & Sauter, 2013, pp. 41-42). It is thereby not factual knowledge, which is focused upon, but capabilities of actors and entities. Especially in networked factories, where personal is highly trained and specialized and smart devices possess knowledge and decision-making capabilities, one needs to identify the relevant knowledge carrier with the capability to solve a problem. In this view, learning factories should provide means to network within and across groups of learners. The learning factory setting can ease initial interaction through collaborative scenarios, which are not typical in a real factory environment.

Learning factories can incorporate multiple theoretical approaches in the development of learning scenarios. The selection of the appropriate theory used to design tasks, instructions, and feedback is guided by the objectives of the scenario. Bloom's *taxonomy of educational objectives* (Bloom, 1956) helps to structure learning activities and materials. It is a hierarchy containing six stages: remembering, comprehend, applying, analyzing, evaluating, and creating. A refinement of this taxonomy expands the six stages with concrete activities and connects the activities to the acquisition of factual, conceptual, procedural, or metacognitive knowledge (Airasian, 2001). A learning scenario should encompass objectives from different stages in ascending order. Learners are confronted with more behavioral (remembering), later with cognitivist (comprehend) and constructivist (applying, analyzing, evaluating) and connectivist (creating) aspects. Assistance systems in learning factories should be used with the educational objectives in mind. Using assistance systems, which only present instructions without being context-aware, could lead to frustration with the learner as they have progressed beyond the stage of remembering and want to actively engage in exploration.

3.3. Multi-modal learning as the preferred learning approach

The didactic concept is understood as a practice-oriented guide to pedagogical work based on subject-oriented learning theory. It guides the use of digital media in the learning scenario. Different media can be used to present the necessary information. Since different cognitive styles prevail in the learner population, there is no one-media-fits-all approach. Some learners might respond better to textual presentation, while others prefer auditive or video explanations. A multi-modal learning approach is therefore preferred.

In essence, multimodal learning environments are such, where students are presented with a verbal as well as a corresponding visual representation of the content (Moreno & Mayer, 2007, p. 310). Another prominent aspect of those more complex learning environments, compared to a classical lecture format or the mere reading of content, is the interactiveness of the environment, where learning depends on the actions of the learner. Moreno (2006) explains this enhanced learning effect with the complex cognitive-affective theory of learning with media, which is based on human cognitive modes of action, its constraints, as well as affective, and motivational components. Its core message about how learning can be fostered is to create a most interactive, realistic, individually motivational, and content-focused learning environment. Basically, study material should be presented in such a way, that several senses are activated and thus the information gets more thoroughly mentally represented. However, using diverse multimedia in itself is not sufficient, what also matters is that diverse modalities, like auditorial, visual and tactile, are addressed, since the sensory memory is limited to one input at a time, respectively (Baddeley, 1992). This means that information in a learning setting can easily be neglected simply due to an overload within a sensory channel (Moreno & Mayer, 2002). Further, learning is increased when the learning material is presented in a coherent, integrated fashion as it would be in real life. For example, when viewing a video where a person demonstrates a certain technique, further explanations should naturally come along with the visual material and not separately after the video, preferably auditorial and not in text form. What might seem trivial is often enough not the case in formal learning settings (Birdwell, Scott, & Koninckx, 2015).

On top of the mere cognitive-stimulating aspect of multimodal learning, these kinds of learning environments include another most prominent facilitating aspect concerning learning. Their interactivity, as well as the possibility to personalize the learning experience can increase the understanding as well as the motivation for the learner to engage with the content. Chen (2008) could show this beneficial effect of personalized learning in the case of e-learning material. In the study, for half of the participants, the learning content could be adapted to the competence and speed of the learner, whereas the other part was confronted with standard e-learning platforms. The adaptation group showed superior learning outcomes compared to those standardized learners. Especially with the technology used in those learning settings, a direct and prompt adaptation according to the learner's individual needs is possible.

The variety of assistance system classes presented in section 2.1 allows a mix of different presentation and feedback options. Multi-modal learning can thus be supported by assistance systems on different levels: content can be presented, learners can be instructed, interaction can be initiated and feedback about the environment augmented. Also, personalization is possible if adaptive assistance systems are used in learning.

Assistance systems, therefore, provide different facetted cognitive representations and augment learning within the learning factory environment. Through immersion and stronger association of the learned content with real situations, learning success, self-efficiency and confidence can be increased.

4. Usage of assistance systems in Learning factories

The potential of assistance systems in learning factories can be assessed by combining the application purpose and the learning objective. The application purpose is derived from the aforementioned taxonomy by Wandke (2005). The stages of assistance system use address the model factory characteristic of a learning factory. The general notion of this taxonomy needs to be specified regarding the didactic concept to match the requirements for learning factories. In each stage, different learning objectives can be pursued regarding learning theories. Using Bloom's revised taxonomy (Airasian, 2001) adds learning objectives to the assessment. A conceptual 6x6 matrix results (see Table 1). Each cell represents a use-case of assistance systems as means to present and explore learning content.

	Stage of Activity					
Learning Objec-	Activation	Perception	Infor-mation	Decision Making	Action Execution	Feedback
Remember						
Comprehend						
Apply						
Analyze						
Evaluate						
Create						

Table 1: Combined Taxonomy of Assistance Systems in Learning Factories

When planning and executing learning scenarios, use-cases are not regarded in isolation but bundled. Thus, learning scenarios capture multiple fields of the matrix. Depending on the purpose of the scenario, different patterns can emerge in this matrix. A process-oriented scenario can address the comprehension objective in all activity stages (horizontal path), in-depth learning on the other hand can vertically transverse the matrix e.g., to learn, apply and analyze production processes through perceptive assistance systems. Other combinations to design learning scenarios with multiple assistance systems for different tasks are also possible e.g. when moving through the matrix diagonally.

The matrix can be used to assess the applicability of assistance systems by different means. First, conceptualizing the assistance system use for a specific objective can be harder in different stages e.g., when combining comprehension with action execution, two conceptually different aspects: the cognitive requirements of comprehension need to be bridged with the haptic requirements of action execution. Secondly, the implementation of the assistance system requires different efforts in each stage-objective combination. This is due to different degrees of interactivity and adaptability; thus, certain combinations can be hard to implement and should be better achieved with different presentation means. Thirdly, the implemented scenario needs to be accepted by the user respectively the learner. This allows a differentiated assessment of assistance systems for learning purposes like age, educational background, or existing production and technology experience can impact the acceptance of certain assistance systems.

The developed taxonomy is partially tested using a case study approach. Cases highlight different paths, objectives, benefits, and obstacles in implementing assistance systems in learning factories.

5. Research Design

To demonstrate the taxonomy and the areas of application of assistance systems in learning factories, a case-study design was chosen. A case study approach is applicable if a real-world phenomenon should be explored and an experimental setting cannot be applied (Yin, 2009). A "case study is an in-depth exploration from multiple perspectives of the complexity and uniqueness of a particular project, policy, institution, program or system in a "real-life" context." (Simons, 2009, p. 21)

Since the application of assistance systems in a learning factory involves technical, cognitive, and social aspects a systematic quantitative study is only possible for distinct, well-defined problems. Due to the multiple perspectives, the possibilities and effects assumed in our taxonomy need to be investigated exploratively.

Case studies offer a structured way to describe, interpret and evaluate a real-life phenomenon (Merriam, 1988; Stake, 1995). Different perspectives can be taken, regarding case study research (Ridder, 2017). In our case, the application of theoretical aspects (learning theory) in combination with assistance systems is applied (Bassey, 1999). Since this is not done exhaustively, the cases are illustrative using storytelling rather than evaluative or interpretive. Furthermore, the cases were derived from scenarios that were implemented independently from the existing taxonomy. The three scenarios were designed with multiple specific educational objectives and purposes in mind.

To situate the case studies, a differentiation according to subject, purpose, approach, and process of case study is proposed (Thomas, 2011).

- *Subject:* We present three cases from our experience in implementing and operating a learning factory. Each case represents a different assistance system and a different educational purpose according to the taxonomy presented above.
- *Purpose:* Each case should be used to evaluate the capabilities of assistance systems in learning factories for the specified objectives.
- *Approach:* We chose a descriptive and interpretative approach,
- *Process:* we conducted multiple case studies spanning different areas of application of assistance systems. The studies were conducted sequentially and described in retrospect.

The case studies were conducted in the learning factory which is part of the *Center Industry 4.0 in Potsdam (CIP4.0)*. Its simulation environment uses a hybrid approach for factory modeling. This approach combines a physical model factory with computer-aided simulation. From a didactic perspective, CIP4.0 uses clearly defined didactic levels (macro, meso, and micro levels). While questions about participation in continuing education are located at the macro level, the meso level deals with the planning and implementation of continuing education projects. On the micro-level, on the other hand, the micro-didactic design of concrete teaching and learning situations in learning scenarios is addressed. Concretely there are learning modules, which combine elements of the model factory, and competence modules to sub-scenarios which are orchestrated to form a learning scenario. This provides a flexible setup of learning situations and allows the actors a high degree of freedom of interacting in the typical factory environment. The participative, human-centered approach indented the inclusion of the individual action problems or (learning) interests of the participants throughout the entire continuing education process (Teichmann, Lass, Ullrich, & Gronau, 2021).

Data about the three cases were collected during the conceptualization, implementation, and execution of three different learning scenarios. Each had distinct objectives, which can be associated with the categories derived from the learning theories. Meeting minutes and interviews were used to gather data in the conceptualization and implementation phase. Observation, log data analysis, and user surveys provided data to assess the execution of each scenario.

6. Cases of Assistance systems in Learning Factories

The cases span different purposes and formats. The first case captures the use of assistance systems to explore different technological aspects and foster group interaction. The second case focuses on the purely instructive side of assistance systems to guide activities and provide process information. In the third case assistance systems address two aspects: they are part of the simulated factory setting as devices used in production and they are means to guide the users' attention through the scenario. The following sections classify, describe, and assess each case.

6.1. Technology exploration

The first case study presents training on the topics of digitalization as a social phenomenon, safety, and security, risks and challenges, opportunities. The one-day workshops were conducted with worker union representatives of different manufacturing enterprises (Teichmann, Ullrich, Wenz, & Gronau, 2020). This learning environment addresses the topic of organizational change (Abele, Metternich, & Tisch, 2019), whereby the main goal is to prepare key decision-makers for concrete and abstract challenges caused by digitalization processes in society and in their organization. Assistance systems were used to guide the users and provide additional material about the technology.

Case 1: *Technology Exploration*	
Learning objective	Development of general understanding regarding digitalization, technology, and organizational change
Learning approach	Experiential Learning, Connectivism, Constructivism
Stage	Motivation, Awareness, Perception, Decision Making
Assistance Systems	AR glasses, tablets, simulator
Scenario description	The training on technology use is characterized by simulated production processes, different work tasks, and situations as well as by the continuous integration of relevant Industrial Internet of Things (IIoT) technologies (e.g., augmented reality (AR) glasses, AutoID technologies, CPS as well as intelligent workpieces and machines). The learners are confronted with a changeover between product variants during the current production process and the associated production process modifications. With the help of AR glasses and tablets, they must calibrate the machines, powder coating, and quality control that have now to be used according to the product specifications and integrate them into the production process. Certain process modifications initiate further changes as a result, whereby the task portfolio is constantly expanded and supplemented by new challenges regarding one's own process competence. The participants communicate with each other and develop collaborative work processes to prevent the imminent stop of the production process. The thematic workshop includes presentations and lectures on different digitalization-related topics and aims to develop the acceptance of the idea and reduce fears and uncertainties.
Benefits	Learners are continuously encouraged to apply relevant IIoT competencies in realistic learning environments and, building on these, to develop their own options for action in critical production situations. The learning concept furthermore includes presentations and lectures on different digitalization-related topics and aims to develop the acceptance of the idea and reduce fears and uncertainties. The acceptance of organizational changes by employees and decision-makers is increased by the fact that they develop a generally better understanding of the changes caused by digitization.
Obstacles	The acceptance of assistance systems in this learning process is age and experience-dependent. Some participants had difficulties, engaging with the new teaching technology. The additional

	workshops were introduced as a reaction. Furthermore, the contents were not customizable, the participant's level of knowledge should be assessed in advance. Participants who have already gained extensive experience with digital technologies may be under-challenged, whereas beginners in the topic may be over-challenged. The sustainability of the knowledge imparted is questionable if the participants cannot subsequently apply their new competencies in their own practice.

Table 2: Technology Exploration

6.2. Tablet-based initial learning

The second case presents the initial learning of manufacturing processes in a simulated environment. This learning environment addresses the production process topic of learning factories (Abele et al., 2019) and has been developed on the example of the production process of artificial knee joints. Two learning scenarios will be presented to describe the advantages of the learning factory. Both were conducted in the context of the simulated production process, but with different experimental settings and objectives. An assistance system (tablet-based) was used to introduce the participants to the process and provide hints during the process execution.

Case 2: Task and process learning	
Learning objective	Development of concrete digital competencies to perform tasks in the context of a concrete industrial process
Learning approach	Behavioristic, Constructivist
Stage	Information, Decision Making
Assistance Systems	Tablet with walkthrough, simulator
Scenario description	Using original noise, pictures, and videos from actual machines, real-world processes of knee-implant production are mimicked as closely as possible. The participants engage with machines with touch surfaces and manipulate workpieces (which are computers with three screens in form of boxes that move on top of the transportation systems). Further, participants use other technical services like scanners and robots, dependent on which part of the manufacturing process they are working on. The focus lies on the use of digital assistant systems in the training phase for a new production process (Vladova, Wotschack, de Paiva Lareiro, Gronau, & Thim, 2020). The necessary tasks of the workers were depicted in the AS (in the form of a tablet), which was specially developed for the experiment, and enriched with

	learning instructions. The test persons had the opportunity to either act independently for each learning step currently displayed in the AS or to press a "help button" at any time to obtain additional information and tips. The participants were divided into two groups and accordingly assigned to two different settings. In the first setting, the participants were given the AS as the only means of orientation and assistance right at the beginning and were taught the production steps exclusively in this way. In the second setting, on the other hand, the test persons received an additional ten-minute introduction by the experiment supervisor at the beginning of the experiment.
Benefits	The use of the assistance system allows completely inexperienced users to start directly in a production process. The aim is to repeat steps and thus internalize them, neglecting other interrelationships in the process. For example, temporary workers or employees who are assigned to certain tasks at short notice - e.g., as a result of job rotation - can benefit from being guided through the production steps that are relevant to them. They are also given the opportunity to specifically request help at each step as well as to go back one or more steps if necessary. The assistance is first provided by the assistance system and - in case it is not sufficient - also by the human trainer. Through the additional introduction to the process itself, which the control group receives in the experiment, constructivist learning methods can also be used. The social exchange is guaranteed here at the beginning and comprehensive knowledge and understanding of the process can be conveyed.
Obstacles	Common to both groups was the challenge of not getting direct feedback on whether the process step was completed correctly. Furthermore, participants in both groups - regardless of whether they found the assist system helpful - missed the social exchange. The teaching of process knowledge at the beginning was also a challenge for the work with the assistance system because this additional introduction affected the purely behavioristic learning approach.

Table 3: Task and Process Learning

6.3. AR guided production

The third case is presenting the supplementing of operational assistance systems with learning promoting components. Part of the concept of the is therefore the integration of learning promoting functions in the provided assistance system, so that work-accompanying learning can be realized in a targeted manner, and thus learning assistance and processing assistance merge. A systematic knowledge transfer is created by information access on different levels, which are predefined according to the learning situation, following the didactic concept, or are available to the learner for free decision. The central instrument of information access is the data glasses, which offer individual access and feedback according to context, learner, and situation.

Case 3: Data glasses for knowledge transfer	
Learning objective	The goal of the scenario is to increase the user competence of the actors to use confidently in the strongly technology-driven world of work, in particular, problem-solving competence through the targeted use of the tools of modern and future production systems using the example of AR-based information access.
Learning approach	Experiential Learning, Connectivism
Stage	Perception, Decision Making, Feedback
Assistance Systems	AR Glasses
Scenario description	The scenario uses a model of the optical lenses' production using I4.0 modules. The process includes several workstations (machines and manual workstations). The actors involved are the workers, foremen, and apprentices. They use mobile assistance systems of system-integrated tablets and data glasses to perform their tasks and thus ensure that production runs correctly. This includes monitoring the equipment with checks on numerous parameters during regular operation as well as dealing with malfunctions (repairs) and organizational turbulence (e.g., rush orders or external reprioritization of orders). For complex workflows, data glasses are used because they offer hands-free execution of work tasks as well as fast and effortless documentation of the situation, making work easier compared with tablets. In operationalization, the necessary work of the worker or foreman is mapped in the assistant system according to the role and individual information needs. This includes suggestions, recommendations, evaluated alternatives, release activities, dedicated checklists, and delegation mechanisms. Possible information accesses are detail views, online documentation, knowledgebase incl. best practices and involvement of a remote expert via remote session. Additional workflows are available for the trainee role, which particularly address the transfer of knowledge by extended feedback (e.g., by the foreman) even in the production process.

Benefits	The data glasses provide the actions of the respective task as a checklist. Reflecting on the current situation, the actor executes the work steps and makes decisions. This forms processing assistance. In addition, the actor is allowed to obtain further information. Likewise, the actor can check the results of his decisions, partly as a forecast, partly as an actual result. The pre- and post-data views provide not only a data-based decision and a reflection of results but also the abstraction of solution principles or the recognition of patterns, which can be reused in similar situations, if necessary, in an adapted form. This systematic knowledge transfer promotes the learning process according to Kolb's learning stages and complements the worker's guidance to a learning assistance system.
Obstacles	Challenges and obstacles identified in the course of numerous simulation runs during training courses and workshops are the accustoming of handling of the new medium of data glasses incl. voice recognition at the beginning and the initially different degree of acceptance of the assistance, as well as initial skepticism about the suggestions of the assistance system, using it fully as a tool and supplementing or changing the usual procedure. Furthermore, privacy concerns regarding employee transparency and fears of skill obsolescence and resulting substitutability of the employee delay immediate full application. Finally, the partial additional effort in authoring regarding the preparation and linking of potential information should be mentioned.

Table 4: Data glasses for knowledge transfer

7. Conclusion and further research

Assistance systems can play an important role in designing scenarios in learning factories. Yet, the need to be selected and implemented carefully. This paper presented a taxonomy, which allows classifying different usage aspects regarding the activity stage and the learning objectives. By combining both dimensions, aspects of the model factory (stage-based) and the learning activity (objective-based) are considered. By demonstrating different paths through the taxonomy, appropriate learning scenarios can be developed, and their applicability can be assessed accordingly. We demonstrated the use of the taxonomy in three cases, where different objectives were met with specific assistance systems. In each case, the benefits, and obstacles, which were assessed point to improvement potentials of each scenario. However, the test of the taxonomy is limited in scope. Future work needs to test more fields and systematically assess different scenarios in the taxonomy to discover combinations and paths which are hard to conceptualize and implement. Furthermore, the cases did not provide insights into the learning success of the participants. Outcomes from the use of assistance systems should be systematically compared between assistance systems and with traditional learning devices.

The presented approach is a starting point for the systematic development and integration of assistance systems in learning factories.

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The continuous acquisition of new digital competences and the development of situational learning assistance systems will become more important than ever in the coming years, because the world of work is becoming more complex, more informative and all above more data-driven. Jobs are changing due to increasing digitalisation, whereby the use of modern technologies must be designed in a way, that employees can continue to work productively in the company despite these changes and benefit purposefully from digital solutions. The research results presented under the main topic „Competence development and learning assistance systems for the data-driven future" address this problem of state of the art technologies in the workplace and their effects on workers. The members of the Scientific Society for Work and Business Organisation (WGAB) present innovative concepts and research results for practitioners and scientists and thus provide valuable input for current challenges.

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