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The 4th industrial revolution – its impact on vocational skills

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ABSTRACT

Within the context of 'Industry 4.0', work organisation and work processes will change, along with ongoing automation and real-time oriented control of production. The same is true for work contents and the interaction and communication between humans and technology, which entail many consequences for users and providers throughout the entire vocational training system.

There are many definitions of 'Industry 4.0'. A comprehensive one is that 'Industry 4.0' is the current trend towards automation and data exchange in manufacturing technologies which are based on digital technology. It includes 'Cyber-Physical Systems' (CPS), the Internet of Things (IoT) and cloud computing, and has an impact on all economic sectors.

One of the highly relevant questions concerns the qualification requirements for employees on the 'shop-floor' and at the middle employment level. Depending on the implementation level of Industry 4.0 in companies, vocational education and training for the workforce is highly relevant and the vocational education system has to respond to the needs and expectations of these changes in the work world. Successful responses of the vocational system to the demands of Industry 4.0 have to focus on curriculum development and training of both skilled and highly skilled workers.

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Industry 4.0; cyber-physical systems; skilled workers; curricula; competence needs; internet of Things; digitalisation

1 Introduction

There is still an ongoing discussion about the impact of digitalisation.[1] One widespread assessment is: 'For the majority of workers and employees, the immediate effects of digitalization are probably not visible yet' (Harteis 2019: 86). In addition, there are convincing indicators for the progress of digitalisation within the economy. More and more companies are running their business with the help of digitalisation, among them Microsoft, Apple, Facebook, Uber and others. Even small and medium-sized companies are increasingly relying on digital technology. An example: in the city of Hamburg, around 92,000 companies are registered. 90% of these companies apply digital equipment to the optimisation of their business and work-processes (cf. Hamburg 2019: 14).

As soon as the automation is promoted with the aid of software-controlled digital signals, then the use of digitalisation becomes important. The use of digitalisation in Industry 4.0 is leading to considerable changes in different fields, driven by an economic paradigm shift which is aiming at the intensifying of automatisation. Industry 4.0, driven by digitalisation, has to be understood as an industrial-political process that reforms both industrial as well as handicraft work. Digitalisation, in the wider sense, is reaching all levels of society through counting and calculating of data necessary for the – often ambiguous – communication of and with machines (cf. Baecker 2018). This expanded understanding of digitalisation underlines the fact that developments will take place which are irreversible.

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The 4th Industrial revolution is one of the most widely discussed technological and socio-economic developments of the modern world with a deep impact on the agenda of education policies and strategies. While there is rather widespread agreement that the 4th Industrial revolution will have a substantial impact on education and training, still comparatively little attention is being paid to the exploration of the current and potential implications of the 4th industrial revolution for the key processes of education and training, and, in particular, for their development. Explorations of the implications of the 4th industrial revolution for the requirements of the initial vocational education and training are of particular interest because of the strategic importance of this sector of education for the industrial development and employment.

Within the context of Industry 4.0[2] it cannot be denied that work organisation and work processes will change along with proceeding automation and real-time-oriented control. The same is true for work contents and the interaction and communication between human and technology. So far there are limited empirical findings on how work task and competence profiles are likely to change[3] as soon as production processes are more digitalised and autonomously controlled and closely net-worked with the help of CPS.

In spite of the currently observable bias on technological developments in the context of Industry 4.0, the employees will be the pivot for a successful implementation. In order to identify the impact of the implementation of Industry 4.0 on skilled workers, reference will be made to the findings of a study in the manufacturing sector which was carried out by the authors and other researchers. The study is well known in the German-speaking countries as the bayme vbm study (2016).[4] The outcome of this study will be supported by a later one in the automotive sector (cf. AUTO 4.0 2019).

2 Aims and core areas of research

The basic aim of a survey in the context of Industry 4.0 is the identification of changed competence demands for employees on the 'shop-floor' and at the middle-skilled worker level of the manufacturing industry (cf. bayme vbm 2016; Spöttl 2018; AUTO 4.0 2019). Thus, the focus is on the qualification requirements for skilled workers who do not have an academic education and those who have achieved a middle level of formal qualification.

The survey (cf. bayme vbm 2016)[5] started from the point of the future role of skilled workers in a world of changed production. It raised the question as to whether an increasingly 'individualized production' would also make work tasks more demanding in terms of technology, organisation and communication. Which consequences would this development have for employees who do not have an academic qualification and thus are hired at lower salaries? The following questions were central in guiding the research work:

1.What are the current and future changes which have been triggered by the introduction of the principles of Industry 4.0 in the manufacturing industry? What is the scope of these changes? Will employees be affected in the future? What are the requirements for controlling intelligent production processes?

2.Which impact does the introduction of networked and dynamic production processes have on qualification, competence and occupational profiles as well as on skilled workers in the manufacturing industry?

3.Which competences are necessary to work within highly automated, networked production systems? What are the consequences of changed forms of work organisation? Are new forms of 'knowledge and skills' necessary?

4.What are the relevant changes in curricula and further training profiles that will be getting in touch with the principles of Industry 4.0? Which shaping principles for occupational profiles and curricula can be derived?

The survey in the described field of application had a multi-level design and was based on making use of qualitative instruments from vocational and social sciences (cf. Becker and Spöttl 2015; Windelband et al. 2012). The concrete background for the survey were the findings of a study on the 'Internet of Things' (IoT) in the fields of logistics and industrial production, funded by the Federal Ministry for Education and Research (cf. Abicht and Spöttl 2012). As mentioned above, this article is based on findings from a current empirical study – bayme vbm – in the manufacturing industry on the implementation of 'Industry 4.0'. The epistemological interest discussed below was pursued with the applied instruments (figure 1).

The qualitative survey aimed at identifying changes at the production level and consequences resulting thereof for the future shaping of curricula, occupational and competence profiles. A total of 124 people were interviewed (25 expert interviews; 59 interviews in six case studies; 40 experts in three workshops):

- Sector analysis: selection with the help of relevant experts in field of research (main criteria: employment structure, branch structure, economical power of branches), sector and qualification and analysis of circa 55 published sources and eight specific company reports concerning the implementation planning of Industry 4.0.
- Expert interviews: the most important selection criteria of the experts were their involvement in conception or developing processes of Industry 4.0 in their work field, or involvement in reorganisation processes of companies or human resource development.
- Case studies: for the selection of the case studies it was important to ensure a good picture of the development of the area/sector in question. The companies were selected by following the employment structure in the sector, by involvement of the company in the implementation processes of Industry 4.0 (this was checked by a small pre-study). The selection process was done with the help of experts in the field, trade associations and trade unions and by analysing statistical material and the presentation of the companies in the internet.
- Expert workshops: participants in the workshops were representatives of case study companies, experts, and persons who were not involved in the survey.

All the expert interviews, the discussions around the case studies and the discussions in the workshops were recorded and afterwards documented (qualitative content analysis/scenario assessments). These materials were used to prepare a comprehensive report in order to answer the questions listed above.

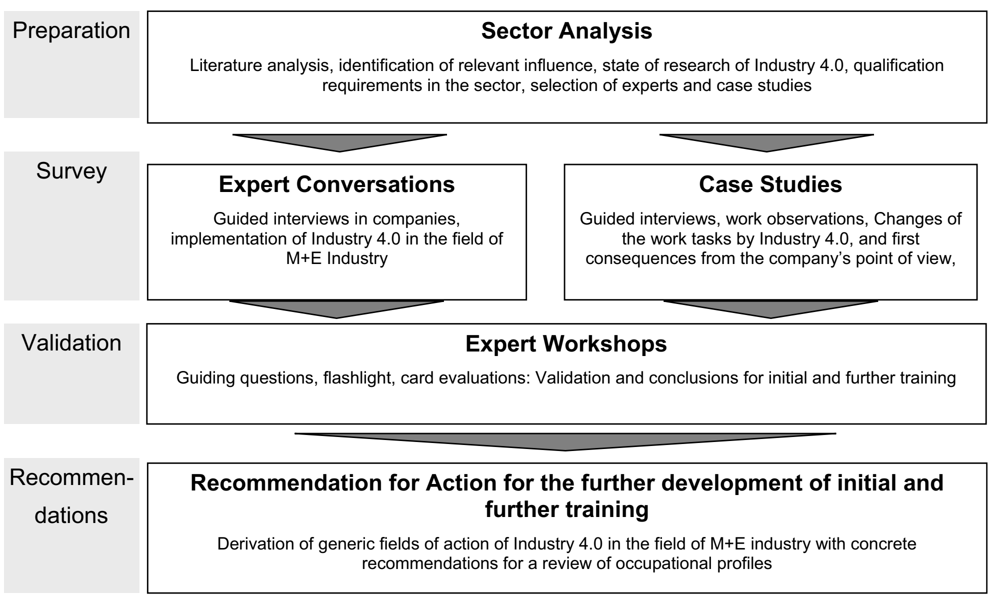

Figure 1. Vocational educational research design and sequence of the bayme vbm study.

The epistemological interest aims at tangible developments on the shop floor in order to identify the real challenges for the skilled workers. Macro-analyses have intentionally not been carried out. On the one hand they were already available. On the other hand the identification of general interconnections of social, technological and work organisational dimensions will, as a rule, not reveal the concrete requirements for skilled workers at the plants. The study thus sought to discover the requirements on a micro-level, on the shop-floor, in order to gain insight into a new shaping of vocational education and training and its curricula.

3 Core of development of Industry 4.0

The developments around Industry 4.0 are at an intermediate stage, yet they are already being considered as the 'fourth industrial revolution' within the industrialised world. The current discussions on this topic are highly diverse: these new developments are partly regarded as just 'old wine in new bottles' (Jasperneite 2012), partly as just an IT hype, yet partly also as the setting for a completely reshaped industrial landscape (cf. Pfeiffer 2017; Brynjolfsson and McAfee 2014; Frey and Osborne 2013; Hirsch-Kreinsen 2013).

This situation aggravates the discussion about ongoing developments. This article, therefore, makes use of a framework which refers to the core trends of the expected impact of Industry 4.0 to competences outlined in the different scenarios of the development of Industry 4.0 (cf. AUTO 4.0 2019; Hirsch-Kreinsen and Itterman 2019; Lee and Pfeiffer 2019; bayme vbm 2016). These scenarios outline two main types of changes caused

by Industry 4.0:

1.Changes in the content of work processes for applied technologies, accomplished tasks, work organisation and other factors.

2.Micro-structural changes of work and work processes resulting in vanishing and emerging occupations and professions.

The first type of change enhances new competence needs and fosters adjustments and updating of qualifications whereas the second type of change often leads to the emergence or the disappearance of qualifications. Both types of change foster different shifts in the structure of qualifications (cf. Tūtlys and Spöttl 2020).

This model connects to the acatech position which claims that

"human-machine interaction is shifting to the human user. Learning machines increasingly adapt to the individual abilities and needs of their users instead requiring them to adhere to a rigid control scheme (acatech 2016a: 1)." This development direction indicates that there will not be a total digitalisation which permeates everything and replaces the human being. Therefore, it must urgently be made clear how skilled workers have to be qualified and what kind of roles work processes in companies may play in the future (cf. acatech 2016b: 3).

The German government has incorporated Industry 4.0 as a new vision project in its plan of action for high-tech strategy and, furthermore, supports the development of so-called cyber-physical systems (CPS) and artificial intelligence.[6] CPS are objects, equipment, buildings, means of transportation or facilities for production or logistical components which contain integrated systems rendering them capable of communication. These systems can communicate via the internet and may use internet services.

Due to their adaptable sensors CPS are capable of assessing the relevant dimensions of a particular environment, evaluating them on the basis of data which are globally available and acting upon the physical world with the assistance of actors. It is thus the intention to apply the technological means of micro-systems and information technology to the creation of open and interconnected systems, which employ sensors to retrieve data on specific situations in our physical environment and to interpret them and to make them available for internet-based services. The interconnectivity between the physical and the virtual environments in CPS gives rise to new dynamic production processes which were not feasible before. This can be regarded as the fusion of physical and virtual phenomena (cf. Monostori et al. 2016) Industry 4.0 is based on the Internet of Things (Abicht and Spöttl 2012; Spöttl and Windelband 2017). Everyday objects in our physical environment are thus connected with the digital world (cf. Hirsch-Kreinsen 2015; Windelband and Spöttl 2013). That is why Industry 4.0 can be regarded as the firm establishment of the Internet of Things through CPS. However, Industry 4.0 follows a more comprehensive concept of interconnectivity which intends to assess and interrelate all steps of a process of creating values. The 'intelligence of interconnectivity' is expected to encompass the whole factory, whereby intelligent machines are supposed to organise the production processes by themselves (Bauernhansel, Ten Hompel, and Vogel-Henser 2014; Brynjolfsson and McAfee 2014) even up to the point of dealing with the logistics involved. Within Industry 4.0, humans hold the central positions of directing and managing the processes (cf. acatech 2016a). This is a crucial task for humankind: "Shaping the fourth industrial revolution to ensure that it is empowering and human-centred, rather than divisive and dehumanising, is not a task for any single stakeholder or sector or for any one region, industry or culture." (Schwab 2017: 4).

The changes in the world of work have a deep impact on the training needs. Three categories are the core of these changes:

- technology
- work organisation
- social and ethical dimensions.

They form the ongoing transformation of the workplace. An organisation of the future is one in which employees will no longer be able to rely on simple skill training or rules of discipline, but development as an integral part of the job will necessitate on-the-job-training as well as retraining in accordance with the demands (cf. Kalio 2019: 170). Workplaces require highly skilled workers for a broader[7] and more technology-driven organisation: Industry 4.0 can rightfully be referred to as a production paradigm since we have on the one hand intelligent factories and on the other hand production and logistics processes which are globally interconnected over the internet. This enables a flow of materials which can be optimised and interconnected to a degree so far unknown.

As a result of digitalisation and enrichment with information, web-based and mobile work- and business processes, as well as services based on intelligent analyses of large databases are becoming more and more important, and are also significantly impacting the design of high-tech work environments and hence the workplaces involved.

This kind of technological development definitely has to be addressed as a long-term strategical project which intends to create intelligent closed processes in production, in the neighbouring fields as well as finally within the entire value-added chain of production. This calls for innovative concepts of interaction between humans and machines in order to direct work processes in the future (cf. acatech 2016a;2016b).

In Germany, this development has been regarded as part of the fourth wave of industrialisation which is commonly referred to as the 'intelligent factory' or 'smart factory'.

This kind of technological development definitely has to be addressed as a long-term strategical project which intends to create intelligent closed processes in production, the neighbouring fields as well as, finally, within the entire value-added chain of production. This requires innovative concepts of interaction between humans and machines in order to direct work processes in the future. The development of Industry 4.0 enables greater mobility of enterprises with regard to the design of work and the employment of skilled labour. It also challenges institutionally based and nationally embedded skill formation systems (cf. McKinsey Global Institute 2017). Industry 4.0 challenges the traditional boundaries of disciplines, knowledge and competence areas that are important for the identification and the definition of the limits of qualifications. For example, the application of sensors and activators within networking of cybernetic-physical systems (CPS) requires interdisciplinary individual and collective competences that integrate knowledge and skills from the fields of machinery production, electronics and information-communication technologies (cf. Gorldt et al. 2017; Grimm 2020). Such an erosion of the disciplinary and occupational boundaries between competences and qualifications is also enhanced by the different features of changing industrial production, such as virtual realities, individualisation and the high flexibility of production processes, the integration of digital, virtual and real dimensions of production processes and an increasing transparency of the accomplished production processes ensured by the ICT solutions.

However, when appraising the effects of Industry 4.0 what very often is missing is a 'systematic look' at the approach in its entirety, i.e. reflection on chains of processes (Thoben 2014). As a result of Industry 4.0, the role of the workforce will undergo considerable change. Yet, it is still uncertain which direction this change will take. It is important to note in this context that compared to the discussion about computer-integrated manufacturing (CIM) in the 1980s, the discussion around Industry 4.0 explicitly addresses issues regarding education and further training, the design of work, as well as the question of an interdependency of technological and social intelligence. The roadmap for CPS calls for a 'Qualifying Initiative for Industry 4.0' in order to enable the employees to acquire professional competence in due time. In these discussions, it becomes apparent that work culture is highly regarded within Industry 4.0 (cf. Ahrens and Spöttl 2018; Pfeiffer 2017).

Kagermann, Wahlster, and Helbig (2013: 57) particularly emphasise that: 'The smart factory contains structures for a new work culture which is oriented at the interests of the employees … Decisions regarding the quality of work are not made by technologies or technological constraints, but by scientists and managers who design and model the smart factory' (man. Thus the target is 'a socio-technological perspective of design, in which the organisation of the work-process, activities for further training as well as architectural technologies and software are in close alternating attunement developed in one go with the focus on the development of intelligent, cooperative, self-organised interactions between the employees and/or the technical operational systems along the entire value-added chain' (ibid., acatech 2016b).

This gives rise to a huge potential for design in spite of or even because of increasing automation and networking. The previous focus on technological determinism is of no importance for these considerations. In this context the question of changing structures of tasks and the implications for qualifications needed as well as the risks of downgrading of employees are highly relevant. So far there are only some empirical findings at the shop-floor level regarding changes in task- and competence-profiles[8] when production processes are highly digitalised and decentrally monitored by CPS. with the result that intelligent products self-organise their pathways.

There are already visions that, in the future, objects will 'negotiate' with each other in order to secure the most efficient process. However, in this context, it is not very realistic to expect autonomous systems of production to arise any time soon (Hirsch-Kreinsen 2013). A high degree of automation also corresponds to a factory without but different levels of automation have to be expected depending on different production settings and needs for flexibility. Furthermore, earlier processes of automation have already demonstrated that the employees will be confronted with changing tasks and contents. At the same time, this has mostly had the effect that simpler manual tasks were abandoned (cf. Kurz 2013; Warnhoff and Krzywdzinski 2018). In spite of the present emphasis on technologies in the context of Industry 4.0 the employees will continue to be the pivotal point for successful implementation.

That is why the focus of the discussion regarding Industry 4.0 should centre around the development of competence, the possibilities for obtaining qualifications, as well as changing task profiles of professionals.

What we are witnessing today is more or less the resurgence of the concept of networking in industrial production in the eighties and nineties of the last century. However, over the last few years, considerable technological progress has been made resulting in the attempts at networking not only becoming more effective in a top-down manner, but also being practised from the bottom up and with the aim that the objects themselves are equipped with intelligence (for example radio frequency identification: RFID with chips). The effects on the necessary qualification of professionals at different levels are not yet completely clear. It is, however, to be expected that the networking between particular steps of the production process and certain emphasis areas with the assistance of data will result in further intensifying the process of production controlled by software. That is why the requirements regarding concepts of qualification will change considerably in order to match the change in the organisation of production processes. The driving forces behind Industry 4.0 (for example experts, institutions, politics) and the companies assume that important innovative steps of implementing Industry 4.0 have to be supported by skilled professionals. Contrary to the approach of computer-integrated manufacturing (CIM) humans have, meanwhile assured for an important role in this process for themselves.

4 Outcome of the empirical studies

Industry 4.0 can be regarded as a change of paradigm which intends to enforce digitalisation, networking and virtualisation in the companies in all areas. Consequently, in addition to Industry 4.0 the terms Economy 4.0, Work 4.0 and Learning 4.0 (cf. Schröder and Urban 2016) are the subject of intensive industrial-political discussions. These discussions explore the possibilities of an increase in digitalisation. Regardless of the issues which are still unclear surrounding the effects of Industry 4.0, IT-security, the protection of data or Big Data, with regards to concrete change in companies, to the impact of digitalisation on occupations, qualifications, the world of work, mobility, productivity, safety at work and so forth, the developments supporting Industry 4.0 are being strongly politically supported (cf. Hartmann 2015a; Pardi, Krzywdzinski, and Lüthje 2020).

The impact of the digital transformation in workplaces is, above all, the subject international debate. The authors Frey and Osborne (2013) have found out that 47% of the workforce could be replaced by computers in the next 10 to 20 years. They are referring to the United States of America where they expect a corresponding change over the next two decades. In terms of methodology, the results by Frey and Osborne are based on interviews of technology experts in several of the professions practised in the USA. The survey of Frey and Osborne concentrates on the technical opportunities of automation. However, even the authors underline that what is technologically possible does not have to be implemented at all costs, given the importance of commercial, ethical and other aspects. Other studies, such as the European survey on competences and occupations – European Skills and Jobs Survey (Pouliakas 2018) assume fewer job losses. Around 14% of the workplaces in the European Union are subject to a high risk of automation. For 35–40% of workplaces, it is assumed that there will be changes in fields of tasks and qualification requirements in the medium term. Dengler and Matthes (2015) have subsequently analysed the potentials for substitution in Germany based on the level of requirements and occupational segments and the combination of these groups and conclude that 15% of all insurable employees are facing a high potential for substitution. However, the study hints that existing occupations and job profiles will also be subject to an increasing adaptation to digitalisation. A complete loss is therefore unlikely. The IAB comment 11/2019 (cf. Matthes et al. 2019: 4) concludes: "There is no evidence that technological progress leads to less employment. However, technological developments have led to structural shifts between sectors and occupations, which can be expected to continue in the future. Digitalisation not only offers potential for substitution, but also for productivity and inclusion."

In addition, the results of a survey carried out by Bonin, Gregory, and Zierahn (2015: i) reveal interesting findings with regard to the fact that, first and foremost, activities rather than occupations will be automated. They are convinced that not all employees of the same occupational group are carrying out the same activities.[9]

Studies which explore the requirements of automation in work emphasise the 'ironies of automation' which describe the dilemma of employees in highly automated environments; employees are involved in a controlling and monitoring function, yet at the same time, because of increasing automation, they have fewer chances to completely understand ongoing processes. This insight is needed to acquire the necessary experience for the solution of problems (cf. Brainbridge 1983). All in all, it has to be assumed that employees in the production process in various fields will continue to play an important role, so it is necessary to qualify them for the challenges they will face. figure 2 gives an overview of the requirements taken from surveys (cf. bayme vbm 2016).

The data in figure 1 reveal that three task areas for skilled production workers are very important: Task area I:

- The handling and operation of, and experience with mechatronic plants and
- The operation and understanding of hybrid plants.

Task area II:

- Carrying out parametrisation,
- Making decisions,
- Keeping complex plants in operation.

Task area III:

- Ensuring process workflows (also when using high-tech equipment),
- Ability to optimise plant functions,
- Evaluation of machine data and intervention in case of malfunctions.

In addition, there are tasks which are not ranked very highly. However, these tasks clearly show that apart from traditional tasks the use of data for the optimisation of plants, the understanding and use of software, as well as decision-making and cooperation in teams are especially important.

This raises the question to which degree areas of production which thus far have been separate from each other, such as machine building and information technology, can be addressed as hybrid clusters of competence in order to monitor intelligent production processes. 'Most probably all employees in Industry 4.0 will have to face significantly higher demands regarding complexity,

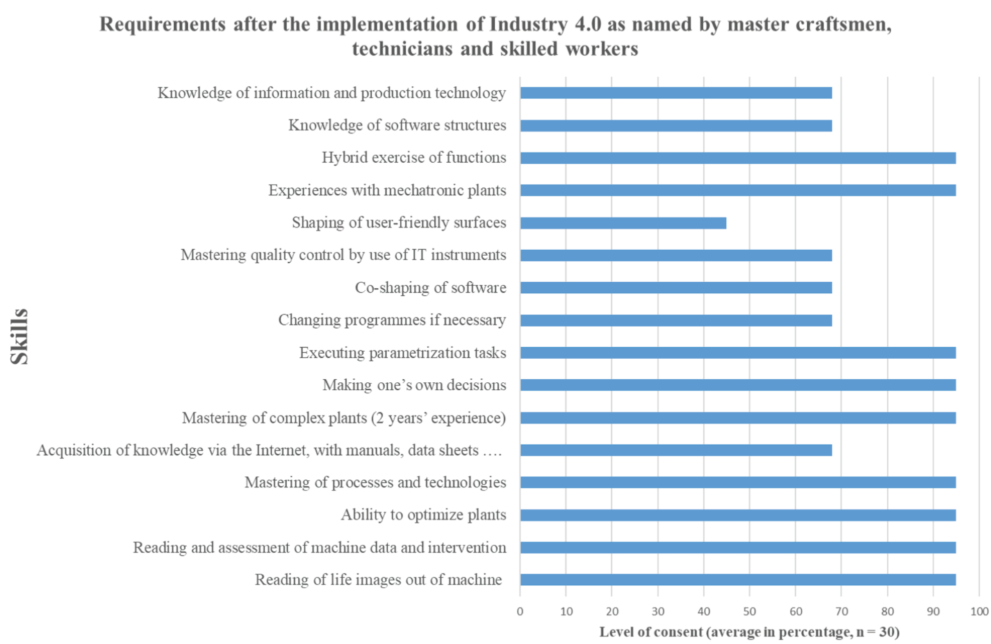

Figure 2. Requirements following the implementation of Industry 4.0 as stated by master craftsmen, technicians and skilled workers.

abstract thinking and problem-solving. Furthermore, the employees expect that they will have to demonstrate a very high degree of self-directed action, communicative competence and ability to self-organise. In brief: the subjective abilities and potential of the employees will be in high demand. This offers the chance for qualitative enrichment, interesting connections with work, increasing self-responsibility and self-fulfilment'. (cf. Promotorengruppe 2012). If companies wish to benefit from these findings, they must train their skilled workers adequately.

For the international competitiveness of any given national economy the efficient development of innovative products, processes and systems of production in the productive trades are highly important. The processes of production as a part of global competitiveness need to be technologically and organisationally further developed on an ongoing basis, since for products, qualities such as sustainability, preservation of resources and individualisation are increasingly in demand. In particular, the development of sustainable products makes it possible to satisfy the demand of the present generation without endangering the possibilities of expansion for future generations. Individualised products for potential customers require the realisation of specific qualities of the production process such as for example extended durability or minimising the consumption of energy. In particular for countries such as Germany with scarce raw material resources, these features are a central factor in the success of the private sector. In this context success in the market is highly dependent on success in translating the concept of an innovative product into market conditions.

Industry 4.0 as a sweeping application of digitalisation is not only a matter of technological possibilities but is a primary economic and politically initiated offensive. This is proven by the High-Tech-Strategy followed by Germany. Industry 4.0 is unfolding its own dynamics, which are driven by the global economy (cf. Kutscha 2020).

It is evident that these innovative technological structures will considerably influence the design of production processes. The translation of complicated and complex 'structures of machining' into the digital and virtual operation of machine tools will change work-processes, since 'dangerous', 'very difficult', 'dreary' or 'easily executed' tasks can be taken over by automated machines. These developments are not altogether new, yet the effects of their introduction change according to different task-profiles, rendering them more or less demanding (cf. Hartmann 2015b), since humans and machines can work together through different interfaces. In these work processes, there is a tendency for more and more parts of human action to be taken over by machines, and this has considerable impact on the activity and the capability for abstract thinking of the employees involved in this process (cf. Markowitsch et al. 2008). It is thus important for vocational education to decode these developments.

The technological foundations of Industry 4.0 such as general connectivity, the internet, sensors, actors and 'intelligent' CPS have resulted in a massive push for efficiency and a reduction of costs for products. The observation of the substitution of cognitive work and of routine tasks cannot remain without consequences for the design of occupational profiles (cf. Hartmann 2015b). This has also been proven by previous waves of industrialisation.

4.1 Changes of work and requirements at the shop-floor level

Figure 3 documents the outcome of a case study of a German supplier in the car manufacturing industry (cf. bayme vbm 2016; AUTO 4.0 2019). Out of the company's 1500 employees, around 60% are working as skilled workers, 30% are engineers and 10% are management staff. The production encompasses around 950 persons. The company manufactures brakes, airbags and control units. The high demands for quality involve detailed documentation which indicates when and where which part was manufactured.

The tasks of skilled workers are manifold as the fields of application in production are frequently changing. The skilled workers must master the following tasks:

- Adjust machines and plants and ensure their technical functions
- Identify malfunctions during trouble shooting and exchange spare parts

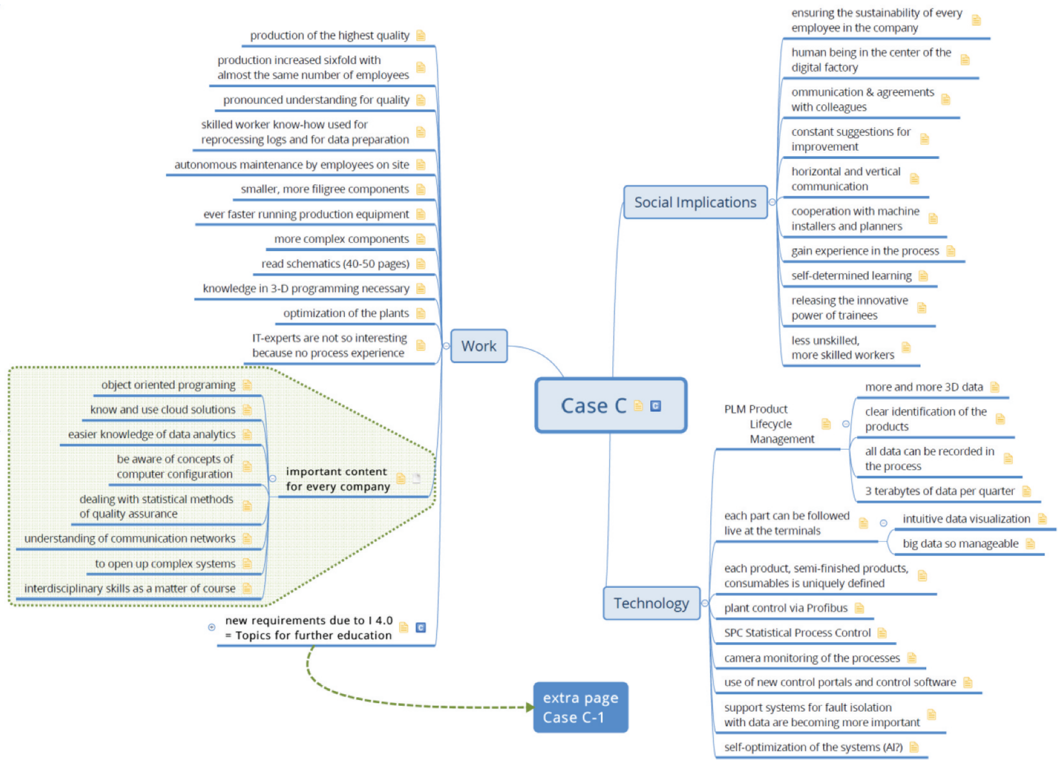

Figure 3. Example of skill requirements of a company (source: case study, Germany).

- Repair damages or in case of severe cases give hints indicate potential causes of damage to specialist teams
- Read and check different combinations of software
- Be able to repair malfunctions in sensors and actors.

These developments allow us to summarise these new task fields for the production industry:
Analysis, supervision, optimisation and extension of production networks and – systems

- Networking plays an important role; optimisation of older plants; overcome breaks between the interfaces (MES, SAP, CAD-CAM); complete registration. Digitalisation of the processes!
- The skilled worker is the user, technicians or master craftsmen co-shape.

Make use of and co-shape IT-supported assistance and diagnosis systems

- Making use of software-controlled assistance and diagnosis systems; access to network technology, Firewall technology, router configuration; ability to analyse data processing processes, identification and repair of malfunctions; understanding of networking processes.
- Skilled workers, technicians, master craftsmen optimise plants and ensure a flawless operation.

Analysis, interpretation and documentation of production data

- Combine data beyond the value-added chain (engineering, operation, maintenance, service, business model; data analysis, interpretation of data; optimisation of work processes; use of knowledge and documentation systems).

- Skilled personnel on the shop floor master the handling of data

Understand and optimise process interrelationships including upstream and downstream areas and their networking

- Integration and real-time synchronisation of processes throughout product life cycles; parametrisation; use of intelligent appliances.
- Skilled workers take over the role of optimisation,while technicians and masters co-shape.

Putting process optimisation into plant operations

- Preparatory measures for the putting into operation of plants and the ensuring of plant functions; cooperation with colleagues (skilled workers, engineers); support process optimisation or workers being able to handle these tasks independently; making use of digital information.
- Skilled workers are in charge of putting the plant into operation and optimising it

Carry out repair of malfunctions and maintain plants.

- Troubleshooting repairs in complex, networked plants; reading and interpreting operational data for trouble shooting of mechanical components, actors and sensors; signal processing; service routines.
- Skilled workers master tasks such as changing lathe chucks, service tasks etc. and repair malfunctions in PLC-
  programs (PLC = Programmable Logic Controller) (partly embedded in networked production software.

These tasks require that skilled workers are continuously further qualified and trained, especially to deal with software.

An analysis of all tasks of skilled workers in production reveals interesting outcomes:

A clear differentiation between the requirements (see above) of

- technology
- work and
- social implications

is possible (see figure 3). This demonstrates that technology is not the only driver of the implementation process of Industry 4.0. In order for implementation to be successful the structure of work organisation and the requirements of work are important. The shaping of work organisation decides which level and differentiation of qualification are needed. When it comes to work organisation quality assurance, dealing with complexity, process optimisation (optimisation of plants), efficient use of documentation, implementation of new systems is very important. It is also important to consider the social impact and the importance of preparing the workforce for these tasks. Communication, cooperation, innovation, higher cognitive skills, acquiring experience in operating complex technology, continuous quality improvement etc. are some of the societal implications the workforce has to be trained for. Another issue is dealing with different kinds of software. This task requires workers who are able to make use of software, who can take care of minor programme modifications or analyse statistical messages based on data which are transported via the software. Operating the latest technology is another issue of relevance but because of the continuous development of the end products a number of strategies and training measures and made use of in process development. Therefore, workers have to be trained to enable them to shape their work successfully.[10]

Based on case studies in companies and expert interviews (cf. bayme vbm 2016; AUTO 4.0 2019), the challenges resulting from the implementation of Industry 4.0 at the shop-floor level can be characterised as follows.

4.1.1 Human-machine interaction

The Realignment of Human-Machine Interaction

Intensive discussions are currently being held about the role of humans in connection with further automation. All statements in case studies and expert discussions indicated that automation must be designed in such a way as to ensure work opportunities for qualified skilled workers in production as shown by the example below:

'In the future, plants and their software will support skilled workers during troubleshooting. Information and analyses will be brought into context.' (Case D[11]).

"Overall, simple work tasks can be automated more easily. Automation today is just a question of money. The higher-quality work tasks, however, cannot be easily replaced."(E 1[12])

The surveys were unable to identify clear trends in the further development of human-machine interaction. However, the risks of a higher degree of automation were clearly highlighted:

'An important development in mass production is the fact that, due to automation, many tasks are geared to plant monitoring. In addition, these processes are highly standardised. This leads to a loss in the sensitivity necessary to safeguard all process sequences. This entails a lot of risks.' (Case E)

The shaping of technology plays a very important role. The question is whether technology is shaped in a way that makes operable by users and whether skilled workers are able to contribute their acquired competences. Key words such as assistance systems for skilled workers and cooperation between human beings and robots were mentioned. Here are some examples:

'Engineers and skilled personnel must also learn to conceive application systems by starting at the level of the users. It is important that they learn to apply technology usefully and manageably. The question must also be kept in mind how to design technology in a user-friendly and operable way. Considerable reconceptualisation is necessary in order to overcome the dominating technology strand up until now. Assistant systems must be easy to operate!' (E 4)

'At the moment there is something like a coexistence between human beings and robots. In this case, skilled workers show the robot where to take a grip. However, the related safety concepts are not fully developed. A collaboration – i.e. human being and robot are simultaneously working on the same work piece – is currently in preparation or even already existent in some cases. Highly complex products, however, are as usual still machined by skilled workers or master craftsmen – by human beings.' (Case A)

Beyond the distribution of roles and control tasks between humans and machines, knowledge distribution will be decisive. Can the expert knowledge of a skilled worker be transferred to a machine? This is one of the central questions answered by a company representative as follows:

'Because of digitalisation, the complexity of the plants is increasing as a direct result of networking. In order to safeguard stable production processes, knowledge and abilities must always be distributed between several persons. This means that it always takes persons who can mutually substitute for one another. These safeguards also imply that process knowledge and product knowledge is saved in data bases' (Case B).

The overall statements made by company representatives and experts show that a further diffusion of Industry 4.0 technologies results in changes in industrial production, organisation and cooperation between humans and machines. Clear or uniform tendencies cannot be identified through the expert interviews and case studies, as developments in the different enterprises studied are following different paths. Company-specific development strands are clearly dominant. All current considerations target the human being at the centre of interest, while concepts for the implementation of this approach still lack wider dissemination. Skilled workers with an occupational-corporate education play a predominant role in the interaction between man and machine, something that statements from all participants confirm.

4.1.2 Synchronisation of the material and information flow

The synchronisation of the material and information flows takes centre stage and the physical world is likely to continue to meld with the virtual world in the near future.

'The interview partner claims that the vision of the production of Big Data from the Cloud will soon be fully automatically controlled but is not yet reality. He keeps on relying on the necessity of the employment of human beings and on taking into consideration all relevant fields of activity. This means that the networking of human beings, means of production, machines and operating materials must be simultaneously considered. According to him, the human being and the process must be coordinated and that this must dominate all steps of approaching Industry 4.0.' (E9)

'Control technology and software are developed at the company. It is estimated that the software will be given more attention in the future. The development of the software is likely to contain the actual know-how of a company.' (Case F)

'The data generated from existing and new machines are becoming increasingly important. Data have to be considered raw material. Data form the basis of new business models.' (Case F)

These statements confirm the continuous transformation at the shop-floor level and underpin the changes. Industry 4.0 is considered a continuation of the constant changes that human beings have always been dealing with in the factories.

'Information that should be at the disposal of skilled workers during maintenance and repair tasks are (according to the interviewee, the author) historical data such as plant manuals, spare parts catalogues and plant documentation. (The interviewee, the author) can well imagine applying Augmented Reality for interference suppression.' (Case D)

4.1.3 Work organisation

Realignment of work organisation: Changes of the organisation of work are at least as important as technological changes. This is underpinned by the quotations below.

'It is crucial to bring together the different groups such as machine operators and engineers. The different groups must get along well. A common cultural basic understanding is necessary. It is, however, still not clear how such collaboration could look like: Bridging of experience worlds, changes of the leadership culture, no more clear structures, temporary working groups. There are many different scenarios.' (E 1)

'Another important element is the development of team competence. Especially during the introduction of elements of Industry 4.0, heterogeneous teams will be formed. Skilled workers, technicians, engineers with or without responsibility *must cooperate in teams.' (E 4)*

These quotations exemplify the fact that considerable changes in the production halls are underway. The statements about the need for skilled workers are, however, less transparent. A closer look at the texts with regard to the developments at the shop-floor level shows that numerous practical changes are considered. Skilled workers without an academic graduation are able to cope with the application, implementation, with problem-solving and comparable tasks. It is, however, unclear whether the same applies to technicians, master craftsmen or skilled workers. Figure 1 summarises these tasks based on interviews with production managers. It is clear that the skilled and highly skilled worker types are of great importance.

The various partial studies by BIBB (Federal Institute for Vocational Education and Training) revealed the central result that digitalisation is 'evolutionary' diffusing into existing work places (e.g. construction machine mechatronics) on the one hand. On the other hand, old work places are eliminated in favour of completely new work environments (e.g. skilled workers of warehouse logistics). The latter no longer work on the shop-floor but on an automated control station (cf. Kock and Schad-Dankwart 2019). The BIBB authors consider these changes at the shop-floor level a challenge which could be met by the initiation of a 'conceptual change' during competence development (Zinke 2019: 269). What is meant by this statement is the introduction of a didactical approach which concentrates on corporate and occupation-typical processes and systems as the starting point of learning.

Based on the empirical work the challenges resulting from the implementation of Industry 4.0 can be summarised as follows:

1.Skilled and highly skilled workers, master craftsmen, semi-engineers (European Qualification Framework – EQF – level 4 and 5), i.e. persons who are well qualified and experienced should be further qualified for specialisations relevant to Industry 4.0. They must be able to master complex processes and to safeguard a flawless operation of plants.

2.The mastering of networked systems with decentralised intelligence, the ability to deal with data and their analysis as well as the ability to safeguard a flawless operation of the plants count among the most important requirements for work on production sites. In all the case studies, expert interviews and expert workshops these competences were required from all representatives with no exceptions. In addition, it is, of course, expected that the still-extant traditional tasks for skilled workers are carried out.

3.Thus far, the setting of priorities for general questions within Industry 4.0 have to be extended by technological priorities (CPS), by issues of work organisation, by questions of work design, data security, programming techniques, trouble shooting and problem-solving with the aid of assistance systems and data analysis (cf. bayme vbm 2016: 3 f.).

The software technical networking and its related CPS elements are continuously becoming prevalent. Along with the increasing diffusion of Industry 4.0, plants and machines must therefore be conceived and dealt with through

- networking
- CP-systems
- the software and
- their embedding into processes.

Thus, the interaction between humans and machines is changing considerably. This is underscored by the more intense use of image processing, the transfer of information via visual processing in different user appliances, the use of videos and of audiovisual language, etc.

In other words: context-related data which provide information on plants, production processes and process operations are dominant. With the aid of integrated sensors and actuators, the behaviour of machines is controlled, analysed and documented. The collected data are processed into information for the plant operator, the worker, and the skilled worker. The data collected again form the basis for tools which are used by skilled personnel according to the situation (cf. bayme vbm 2016: 3 f.).

This amounts to the question of how Industry 4.0 will change the organisational processes and thus the hierarchies in companies. There are not many unambiguous research findings available in the literature. Therefore, it still remains unclear how certain decision-making processes will change at the skilled-worker-level. Is there still room for co-shaping by human beings in Industry 4.0 or will Industry 4.0 promote a 'Taylorism 4.0'? The developers and the drivers of the idea of Industry 4.0 continue to emphasise that they are aiming at a cooperative interaction between all levels. Humans should be given the chance to exert influence on the shaping of their work within production. Kagermann et al. comments:

'The Smart Factory contains opportunity structures for a new work culture which is oriented towards the interests of the persons employed. [...] Neither technology nor technical constraints should decide on the quality of work but scientists and managers who will shape and implement the Smart Factory. What is required in this context is a socio-technological shaping perspective within work organisation, further training activities, as well as technology and software architectures with a close mutual coordination. They should be "seamless" and focus on enabling intelligent, cooperative, self-organised interaction between the persons employed and/or the technical operation systems along the entire value added chain.' (Kagermann, Wahlster, and Helbig 2013: 57).

4.2 Trends of the changes and consequences for skilled workers

The results of the studies (cf. bayme vbm 2016) show that the current state of the implementation of 'Industry 4.0' allows for the definition of the development of the need for skilled workers. However, all findings of the studies demonstrate that employment opportunities for less-qualified workers will decrease along with the implementation of 'Industry 4.0'. A higher need of companies for trained skilled workers and academically qualified staff is predicted. The figures mentioned here were, however, only rarely collected in an empirically valid way.

Based on our own surveys, the following tendential statements about the future need for skilled personnel can be summarised as follows (cf. bayme vbm 2016: 44; Autor 2015; AUTO 4.0 2019):

1.Trend A: Companies without Industry 4.0. No changes in direct production, however, in indirect production (e.g. work places for the future implementation of Industry 4.0).

2.Trend B: Companies with a low Industry 4.0 depth. Stagnation or a slight increase in highly-qualified skilled personnel such as skilled workers, master craftsmen, and technicians as well as a noticeable increase in productivity.

3.Trend C: Companies with high Industry 4.0 depth. Increase by 20 to 30% in the higher qualification levels (well-qualified skilled workers, master craftsmen, technicians – level 4 and 5 of EQF). (Substantial) reduction of low-qualified workforce (semi-skilled and unskilled).

These trends show that skilled workers with a high-quality initial and further training which is oriented to Industry 4.0 will probably have very good employment and career opportunities. This is contradicted by some experts who state that the skilled worker will have fewer opportunities or even at risk due to the developments towards Industry 4.0. Nevertheless, this group is competing against academically trained persons when it comes to planning and conceptual tasks. As for other tasks such as trouble shooting and repair, putting into operation and setting up as well as maintenance and repair, skilled workers with an occupational training in metal- or electro-technology with a focus on software-based networking on the shop-floor cannot be replaced and are highly valued, even more so if they have three to 5 years' professional experience. The case studies underlined that this is above all rated favourably by companies with highly complex plants. Most recently, with the putting into operation of plants, skilled workers with their occupational training can safeguard a continuous operation of the plants, provided they have already learned 'to start thinking from the software' (bayme vbm 2016: 44).

The statements about the worsening employment opportunities for semi-skilled and unskilled workers in our survey match the statements given in other scientific studies. This group does not have the competences required for work at complex high-tech plants. This target group makes up for about 15 to 20% of the production workforce in the manufacturing industry according to region and branch and seems to be the losers in the development of Industry 4.0.

The bayme vbm study (bayme vbm 2016: 85; Spöttl and Schulte 2019) ultimately identified four lines of arguments for the need of qualification and competence levels required for skilled workers in maintenance departments for work with networked plants. The study also indicates contents required for qualification and competence development:

–One line of argument was that it seems to be impossible to qualify all persons working on a general level (generalists) to do difficult tasks (in the context of Industry 4.0) or to repair all of the malfunctions. Therefore, wider and more fundamental initial training is favored. After several years of work in the company, they can then be trained as specialists in advanced training courses. In this light, the thesis was formulated that generalists are becoming less important.

–Another line of argument was that the qualification of specialists with particular IT-knowledge often impacts the internal hierarchy of companies. For example, it is not unusual for a person who has undergone continuous advanced training and even specialized in IT-technology to be eligible for a team leader position rather than taking on the role of a qualified academic. Master craftsmen are already well qualified for leadership tasks and thus qualify as team leader candidates.

–In a third line of argument, it was stated that the requirement level for skilled workers in production is usually very high as well as broad. Individual persons or generalists cannot necessarily complete given tasks. A typical solution is for companies to organize maintenance in teams composed of differently qualified specialists. As a rule, technicians fill crucial positions, contributing professional experience combined with high technical qualifications.

–An especially interesting line of argument was the fact that, in highly automated plants, the software is the interface for all technical solutions. In this case, all tasks, especially service, maintenance and repair, have been structured around software tasks. Highly qualified technicians are necessary to safeguard this software-technological access to plants, while programming is left to the engineers.

These remarks suggest that a sharp differentiation between mechanics and electrics is no longer made. IT-based tasks in maintenance are clearly increasing. The above-mentioned task profiles are mostly an integration of partial tasks, often in connection with interdisciplinary cooperation within a network, based on a high grade of autonomy. Another indication is the ever closer interrelationship of technological units such as CPS and work organisational structures in order to optimise maintenance tasks.

As demonstrated by the empirical outcome – see chapter 4.1 & 4.2 – the interaction between man and machine is changing considerably. This is underlined by the more intense use of image processing, the transfer of information via visual processing in different user appliances, the use of videos and of audiovisual language, the operation with hybrid technology, the manifold tasks (see), the work in teams, the capability to optimise processes, the software-based monitoring of plants, etc. This requires competences which have so far not been considered relevant. The broad competences outlined in table 1 count among the basics for being able to deal with Industry 4.0.

Based on empirical work in the bayme vbm study (bayme vbm 2016) and of the project AUTO 4.0 (2019), the following competences were generated:

- broad competences (as 'new basics')
- context-specific competences for the work in the plants and
- 'abstract' competences for the theoretical reflection in different areas.

The respective competence levels are closely linked to the manifold individual competences for the accomplishment of tasks. The latter are summarised in an Industry 4.0 competences table (cf. table 1). They provide an orientation for the design of learning processes for competence development.

See attachment

5 Challenges for occupational curricula in Industry 4.0

Apart from results for the diffusion of Industry 4.0 technologies and forms of work organisation, further results of the study are available with regards to the changes in skilled work at the shop-floor level. These changes have a considerable impact on occupational curricula and will be outlined below.

5.1 Curriculum development

The empirical results outlined are chapter 4.1 (for more details see bayme vbm 2016) dealing with changes in coping with work tasks and work processes by skilled workers below the academic level. Based on the manifold changed work requirements identified, nine fundamental occupational fields of action which are relevant for Industry 4.0 were generated from the empirical fields of action. These will be described below.

These fundamental occupational fields of action underline those which are 'new' and relevant for manufacturing curricula as a result of Industry 4.0 and the related CPS. A fundamental field of action in Industry 4.0 is the field of work processes for skilled workers which has been extended by Industry 4.0 and which has been identified with the help of empirical studies in companies. After the

Table 1. Different Type of Competences Relevant for Skilled and Highly Skilled workers.

The 'New Basics' – Broad Competences
•Learn to think starting from the software,
•Get to know network structures,
•Learn how to master Big-Data technologies,
•Learn how to work with a variety of data formats,
•Understand and master processes,
•Learn how to take over more self-responsibility,
•Learn how to cooperate and communicate better,
•Learn how to initiate innovations,
•Learn how to use clouds, integration of various machine data/manufacturer data,
•Understand and consider the environmental and social impact of technology choices and innovations,
•Learn to use data as raw material', to use it and to attach more importance to it,
•Make use of innovation potential!
•Support shaping competence!
Context Specific Competences
In plant operation, however, it is important that persons develop further in the following areas of competence:
•Problem solving,
•Understanding of integrated systems and their interconnections,
•Linking of different system controls,
•Think and work across disciplines,
•Getting involved in new tasks,
•Application of IT technology as a tool,
•Necessity to think through the processes, to master processes,
•Mastering multifunctional plant operation,
•To work in the delimitation of space and time,
•Consideration of the entire value chain,
•Maintenance, monitoring, care of drive technology,
•Third hand' (e.g. lightweight robots) will gain importance in the industrial context.
'Abstract' Competences
•Creativity, Creation, Critical thinking,
•Communication, Collaboration (in teams),
•Modelling skills, Analytical spirit,
•Data gathering & mining,
•Respect of procedures,
•Relational communication skills, Investigative character,
•Lateral thinking, Curiosity,
•Leadership, Innovative management,
•Vision and communication,
•Understand business problems.

implementation of Industry 4.0, companies have, in part, already reached an advanced stage. A fundamental 'field of activities' describes new requirements and work processes for those tasks (e. g. plant monitoring) which are typical for an Industry 4.0 environment. The overall nine fundamental 'fields of action' which could be generated represent a reference system for curriculum development which will then help to describe and characterise the new conditions based on Industry 4.0. The reference system can be used to check whether existing occupational curricula should be changed and if new ones need to be established in order to include them into vocational education and training.

It is recommended to make these nine reference points the foundation of curriculum development. The points of reference delineated by Industry 4.0 are related to the field of manufacturing and the work processes which dominate it. They thus offer optimal points of contact for work-process based curricula.

5.2 Description of the fundamental 'fields of action'

Plant engineering

The planning of new automated plants is, first and foremost, a task for engineers. However, companies are increasingly assigning these tasks to mixed teams including specially qualified skilled workers. Together with the engineers, they must select plants suitable for production. An important issue is the fact that skilled workers are confronted with the networking of plants at a very early stage. Within the framework of the planning process, they can already begin to acquire knowledge of the function of the plants and options for networking which they can then later use to ensure the operation of the plant as well as for troubleshooting. Planning processes can increasingly be simulated with the help of Virtual Reality. Virtual Reality allows the imaging of a realistic production system in order to simulate the behaviour of the cyber-physical production system and to explore it in an interactive way.

Target perspective: simulation of plants

Plant installation

The installation and refitting of automated networked plants mostly assigns coordinating tasks to engineers while skilled workers handle the actual technical installation. With the help of the engineers, they learn the exact interrelationships and functions of the individual steps in work processes at the plant as well as their integration into the overall production process.

The network structures within the value-added chain and the use of sensors and actuators are planned and realised in an exacting manner. It is also important to consider all preceding and subsequent processes and to make sure that all data which is important for the overall process (programs, interface configurations, statistical data, data for quality check and networking) can also be processed by skilled workers.

Target perspective: plant networking

Set-up of a plant and putting it into operation

Plants must be set up prior to being their put into operation. Tasks such as the setting of a zero point, calibration, the balancing of the start position, a disruption-free data transfer, the correct display of data on the control monitors are tasks that are handled by skilled workers, who are supported by engineers.

The putting into operation of automated plants and their networking is done in close cooperation between engineers and skilled workers. The engineers have to ensure that the necessary programming functions and interfaces within the production system are working flawlessly. The skilled workers, on the other hand, must make sure that all mechanical, hydraulic, pneumatic, electrical and electronic functions are safeguarded so that the plant can operate flawlessly and that it can be integrated into the production network.

Target perspective: Ensuring the data availability of sensor, actuator and process data in production systems (PPS, MES, SCADA, ERP, SAP).

Plant monitoring

The monitoring of plants – also of several plants simultaneously – is among the most important tasks for skilled workers. Above all, the flawless operation of plants must be safeguarded. This means that the data which is available in real time must be continuously monitored, analysed and evaluated and the overall operation of the plants must be monitored and corrected if necessary. The monitoring of noise generation by machines is as important as data providing information on production monitoring, as well as production quality within the production processes and the products to be manufactured.

Target perspective: monitoring, analysing, and evaluation of real-time data

Process management (visualisation/monitoring/coordination/organisation)

Another important task for skilled workers for plant surveillance and plant operation is to safeguard continuous process flows. This means that skilled workers must continuously monitor processes. In case malfunctions are identified they have to repair them immediately or to suppress them altogether through preventive maintenance.

One of the most important prerequisites for these tasks is an overview of the controlling systems for the entire plant, a sound knowledge of the functions, flow and operation of the plant as well as close observance of the monitoring systems. The skilled workers must be able to read, analyse, and interpret the data transmitted via these systems.

Target perspective: guarantee process safety by process monitoring and repair of malfunctions

Data management (dealing with operational data/access to software/parametrisation/programming)

Reading, analysing, and processing of machine data and their preliminary data are another important task for skilled workers. Data are of great importance for the setting-up of a machine and for a quality-based operation of plants.

Skilled workers must be able to read, analyse, and interpret all relevant operational data (loads, machine and consumption modes). Deviations from standard values have to be identified and dealt with immediately in case of malfunctions. The statistical process control (SPC) in networked production systems is no longer just focused on an individual machine but more and more on entire production sections under the responsibility of the skilled workers.

Skilled workers have to focus their thinking

- by starting from the processes and
- based on the software

and thus optimise plants and their functions. This requires an entirely different understanding compared to mechanically-electrically operated plants. This new understanding is highly relevant for both the operation and the optimisation of the plants as well as their integration into the overall production process.

An efficient plant operation calls for skilled workers to carry out parametrisation tasks on their own. The correction of programming sentences and/or data analyses are also part of their field of responsibility.

Target perspective: safeguarding machine data for plant quality operation, analysing operational data and optimising processes.

Maintenance

The tasks for skilled workers encompass the simple maintenance tasks needed in to safeguard a flawless plant operation. This means that they must have access to the function of plants and must be able to cope with maintenance tasks (metal-technological, electrical, IT-based) in plants composed of different technological systems. Difficult repair tasks are exempted from their area of responsibility. The maintenance tasks also encompass preventive maintenance based on the recording, processing, and visualisation of operational and production data and should be able to be applied at the production work places at all times. In addition skilled workers must also master virtually-organised maintenance tasks and must apply assistance systems for trouble shooting, documentation and knowledge transfer.

Target perspective: preventive, predicted maintenance, multi-functional machines, assessment and use of different data and data formats.

Repair

Difficult maintenance and repair tasks in networked plants and for individual machines are, as a rule. carried out by maintenance teams. These teams specialise in dealing with such tasks, including IT tasks such as network analyses or IT-guided trouble shooting. They also master procedures for the identification of malfunctions (data analysis), causes for malfunction as well as their repair in complex, networked plants.

Target perspective: Considering repair interdependencies which rely on networking and the IT integration of machines and plants; software updates.

Trouble shooting and repair

As soon as malfunctions occur – e.g when they are caused by flawed products or process flows – skilled workers must be able to identify and remove possible causes. This implies that they are able to master diagnostic procedures which not only encompass mechanical and electrical/electronic basic functions but also the digital control of the production process. This is why malfunctions can no longer be identified and repaired directly at the sensors, actuating elements or cabling but rather via IT-systems or within the networking of the production.

Target perspective: diagnosis, trouble shooting in networked plants

6 Summary

Apart from the development and basic facts described here, the future relationship between human and machine must still be clarified. Competence development must go as far as ensuring that human beings keep their dominance over machines. This is a very important educational task for TVET. This task must be accomplished even if it is opposed by economic interests. In order to meet this goal, deepened, object-related as well as communicative competences must be imparted (cf. Bakar et al. 2014; Spöttl and Becker 2013). Curricula guidelines are an important tool for ensuring this task is required in education and training.

The individual waves of industrialisation have had a considerable impact on qualifications and standards of qualification. In the first wave, standardised qualifications were of no importance, instead the focus was on everyday qualifications and semi-skilled qualifications in connection with the substitution of human physical strength through machined processes of production. The second wave of industrialisation already increased the demand for qualified work. For training purposes industry introduced skilled and semi-skilled occupations and, in particular, a high number of highly specialised occupations. For the third wave of industrialisation the model of the autonomous professional worker became the guiding point for the occupational concept and simple semi-skilled occupations lost their importance. In industrialised countries, the number of training occupations was reduced considerably and many occupations were merged into 'core occupations', in particular in the manufacturing industry. At the centre of designing policy for the new arrangements of occupations which accompanied the third wave of industrialisation was the concept of 'open, dynamic professionalism' (Brettschneider and Schwarz 2015), which resulted in a new design of the occupational profiles. During this period and afterwards manifold concepts of differentiation and flexibility were developed which allowed for closeness to the actual work environment (cf. Spöttl and Blings 2011), the open design of occupational profiles and a modern professional orientation ('Beruflichkeit') when designing occupational structures.

For the fourth wave of industrial development answers about how to design initiatives for initial vocational education and further training still have to be found. Yet it seems to be advisable to continue with work-process oriented approaches, since this will ensure closeness to the work environment, openness of design and a modern idea of professionalism when designing occupational profiles. Further relevant topics are software orientation, technical networks, CP-systems and their embedding in processes. Beyond these skills, social competence such as cooperation and communication in heterogeneous teams and taking over responsibility is becoming more and more important. This has a deep impact on curriculum development.

Compared to the outcome of the studies on 21st century skills (Griffin, McGaw, and Care 2012) the result of the bayme vbm (2016) and Erasmus+ (AUTO 4.0 2019) study are more differentiated. Under the term "broad competences (cf. Spoettl and Loose 2015) a range of 21st century skills are confirmed for TVET as well. But all requirements are linked around the domain which should shortly be characterised as work process. It is remarkable that work processes are currently changing profoundly as a direct result of CPS in all elements of the world of work.

The future research agenda in this field is both broad and rich. The advent and development of Industry 4.0 creates many new and unexplored challenges and requirements for the currently widespread competence-based approaches in VET curriculum design, provision of training and assessment of learning. The changing role of VET teachers and trainers and their competence development in the context of Industry 4.0 is another important research field, as are the implications of Industry 4.0 for the development of qualifications and qualification systems in the sectors of economy and countries.

Notes

1. The term can be understood as the technological dimension of Industry 4.0. Following a contrary discussion around these terms in recent years, a sort of consensus has meanwhile emerged around the universally quoted term 'digitalization'. Although this term rather underlines the technological variant of the development, digitalisation mentioned in this article is understood in a sense of a 'digital networking' which has both a technological and a work-oriented and societal-political orientation. Thus it allows the opening of the discourse. Digital networking thus understands that, machines, plants, products, computers, software systems and humans are intelligently linked with each other and can exchange real-time data. The advocates of this development promise above all are expecting a more efficient production and use of products and services. An example taken from the private life are the so-called fitness bracelets which can only develop their full performance when linked to the Internet (cf. Becker and Spöttl 2019: 569).
2. The term Industry 4.0 was coined by Kagermann, Lukas, and Wahlster (2011) and communicated for the first time in 2011.
3. With a view to several occupations and sectors, the Federal Institute for Vocational Education and Training in Germany has presented a number of studies on this key issue. An overview of the results can be found in Zinke (2019).
4. The study is called „bayme vbm (2016) and most of the empirical work was done in 2015 und 2016 in the German manufacturing sector (metal and electro industry). Beginning in December 2019 the study has been continued in a 2nd phase.
5. The AUTO 4.0 (2019) study followed the same approach.
6. This strategy must be seen as an answer to the entanglement of industry and the Internet in the USA. Meanwhile, it is developing its own dynamics, driven by the global economy(cf. Kutscha 2020).
7. This includes social and ethical dimensions.
8. Since 2019 in Germany such studies are available from BIBB (cf. Zinke 2019).

9. These forecasts should be interpreted with caution when it comes to vocational education and training. The reason for this is that a high aggregation level had been chosen for the analyses of activities. Therefore the results are only adequate for the assessment of occupational profiles to a limited extent.
10. The outcome of the six case studies in different types of companies show comparable results but different structures of requirements.
11. The denomination of cases such as Case A, Case B etc. refer to the companies surveyed within the framework of the bayme vbm and AUTO4.0 study.
12. The abbreviations E1 to E15 are used for the codification of expert statements within the same vbm study.

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