Research Article

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Actual Practices for Addressing Requirements of Digitalization in Vocational Education and Training

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Abstract: Existing research on digitalization and Industry 4.0 consistently shows a significant and lasting impact on social coexistence, economic development and work design. It is therefore becoming a central issue to analyze the technological, economic, social and work-related consequences in more detail in order to gain a deeper insight into the requirements to be expected. In this context, TVET (Technical Vocational Education and Training) becomes highly relevant to train skilled workers and make them fit for the changing industry. Answers should indicate which occupations and competences are relevant to the mentioned workers. The knowledge identified via empirical work will be used to draw conclusions about the effects of the changes of work on vocational training and leads to proposals for a future-proof and practice-oriented design of occupations in industry. The core of the qualitative and quantitative empirical survey was based on four research questions. For the study itself, occupational scientific instruments were used for surveys on the shop floor and qualitative interviews were conducted with the selected companies.

Keywords: digitalization; industry 4.0; occupation; sociotechnical model; skill requirements; competences

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1 Introduction

The process of industrialization has been going on for 250 years and consists of a frequently changing, complex network of operational, organizational, socio-institutional and political-economic arrangements, that are also reasonable enough to initiate technical innovations (Brödner 2016). This development is accompanied by social change, a detailed division of labor within companies, and, overall, increasing productivity and lower labor costs. The actual work has considerably changed in the process of industrialization and digitization (cf. Shajek and Hartmann 2023; cf. Kravets and Bolshakov 2024).

What has changed in the long term?

- mechanization and automation of professional manual labor and
- computerization of brainwork (knowledge work) with the help of algorithmic signal processing. Digitization and artificial intelligence are driving the change process forward (cf. Brödner 2016).

The scientification of production and, above all, the process of automation support the process of digitalization, which is further advanced with the help of computerization. Brynjolfsson and McAfee (2014) underscore the importance of the term “digitalization”, whereby it is not sufficient to speak only of digitalization in the sense of a technical process.

Digitalization not only encompasses digitally controlled physical processes that are equipped with interfaces to humans or vice versa (as is the case with machine control systems such as CNC programs, freely programmed controls, drive control systems for drive systems). What is new is that many digitally controlled processes are networked horizontally and vertically across company boundaries via the Internet (e.g. the Internet of Things and Services, cf. Bremer 2017). This way enables data exchange that supports work processes and helps to shorten production time (cf. Bolwin et al. 2023). Security issues play a prominent role in data transfer. These must be considered at all stages of Industry 4.0 implementation (cf. Maruthi Prasad and Bharathi 2025: 45).

In addition, these processes are supported by the mechanisms of artificial intelligence (AI) (cf. Meyne et al. 2025). This is creating completely new spaces for interaction between machines (e.g. multi-agent systems) and between humans and machines (cf. Becker 2016; Becker et al. 2022a; cf. Deshevov et al. 2024). Some examples:

- linking of products and information (e.g. via RFID chips),
- high speed of information transfer (“broadband”),
- unlimited storage options (“cloud”/“big data”),
- virtualization of devices and products (“cyber physical systems”),

- rapid processing of a large volume of information ("real-time processing, big data, computer farms"),
- objects that communicate with each other ("embedded systems"),
- globally available data and services ("smart technologies"),
- optimization and control of processes,
- collaboration in heterogeneous teams,
- creativity in problem-solving processes.

The understanding of the term "digitization" used in this article also includes the effects of the practical use of AI and regards "Industry 4.0" as an application of digitization in the industry. This is intended to underline the special features of these forms of digitization that are relevant for work in production.

This understanding highlights the social relevance of the change process. The consequences are: altered structure of interpersonal communication in human-machine interaction and machine-machine interaction with their significant effects on the shaping of work and its organization.

2 Trends in Digitization

Digitalization is a contradictory process. On the one hand, it can be used as a rationalization strategy with significant risks for employment and working conditions. On the other hand, digitalization enables the humanization of the world of work, prevents deskilling and could contribute to demanding work that promotes learning. In addition to this polarization, "hybrid scenarios" play an important role in many companies, combining very different developments, whereby work intensification, job losses, deskilling or even higher demands on competences are playing a role (cf. Windelband 2023: 196; McKinsey 2017). However, it remains to be seen whether the use of technology and differentiated work organization in digitalized companies pave the way for humanized work. This will depend on the orientation of work design and the availability of the required skilled workers. In any case, vocational training is a key element in tapping the potential for a humane orientation of digitization. It is crucial that it is not just about dealing with technical solutions, but that the dimensions of the socio-technical model come into play (see Figure 1), if only to strengthen the concept of the profession.

The development of a digital economy tends to increase the importance of relevant skills as a central source of trust between producers, service providers and customers (Tirole 2016). At the same time, the digitalization of the economy and the onset of the fourth industrial revolution also potentially entail significant socioeconomic risks that cannot be ignored when analyzing the implications of the required

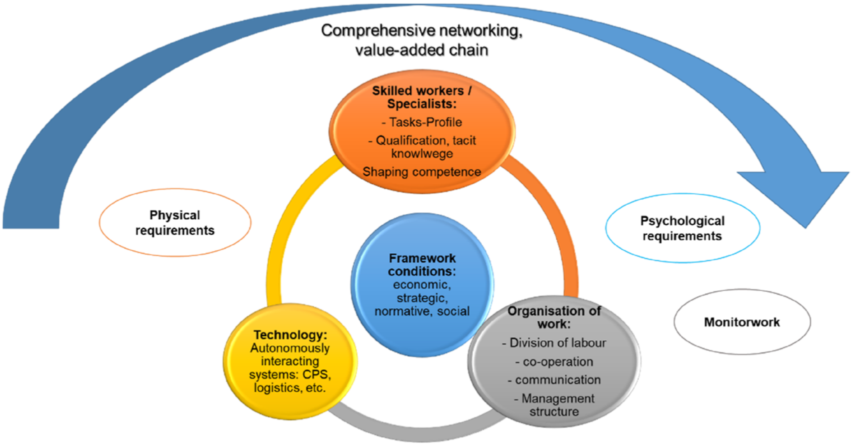

Figure 1: Sociotechnical model (cf. Hirsch-Kreinsen 2014; cf. Hartmann and Shajek 2023).

skills transformation and development trends. Thus, the type of skills needed is strongly influenced by the respective work organization. The advent of Industry 4.0 has brought about significant changes, particularly the individualization and increasing autonomy of technology in the execution of work, and possibly the fragmentation of many workplaces into micro-jobs (ibid.). This has a profound impact on the socio-economic equilibrium, not only on the three pillars of the model shown in Figure 1, but especially on the social, economic, normative and strategic framework – a development that, as Kutscha (2022) argues, illustrates how digitalization in the capitalist mode of production is evolving into a hegemonic model, where digitalization technologies threaten to dominate the educational, economic and personal spheres of life. For example, the kind of competences which are needed is strongly influenced by the particular work organization; e.g. changes brought about by the advent of Industry 4.0, especially the individualization and growing autonomy in the execution of work, as well as the fragmentation of many jobs into micro-jobs (cf. Tirole 2016; PwC 2015). This has a deep impact on the socio-economic balance if it concentrates on one of the three pillars of the model which is shown in Figure 1.

The changes in the three pillars can be reliably analyzed. However, the conclusions drawn from them are crucial for the effects on society. Stalder (2018) uses the term "digitality" to describe this complex of interrelations and effects more precisely.

It is currently still unclear whether a digital Taylorism (Taylorism 4.0) will develop, based on the standardization and subsequent digitalization of the execution of complex work processes and "highly qualified" tasks. Such a direction of development would accelerate the replaceability of highly qualified workers. The autonomy of medium-skilled and even highly skilled employees would also be called into question in this case due to the increasing digital control of the execution of work tasks (Tirole 2016).

Schwab (2016, World Economic Forum 2025) indicates that the implications of the digitalization for jobs and employment depend on the interplay between the destruction effect, when the technology enhanced disruption and automation substitute capital for labor thus forcing workers to seek for other fields of application for their skills and the capitalization effect of new jobs, occupations and businesses created by the demand of new goods and services. According to Schwab (2016), the innovations of IT and other disruptive technologies raise the productivity by replacing existing workforce, rather than creating new products requiring more labor to produce them. Such development leads to growth of employment in the high income knowledge-intensive and creative jobs, as well as in low income manual occupations that cannot be easily automated. At the same time, significant reduction of middle income routine jobs is going on (cf. Schwab 2016). In the latest study of the World Economic Forum (2025: 6), these statements are confirmed: "Skill gaps are categorically considered the biggest barrier to business transformation by Future of Jobs Survey respondents, with 63 % of employers identifying them as a major barrier over the 2025–2030 period. Accordingly, 85 % of employers surveyed plan to prioritize upskilling their workforce, with 70 % of employers expecting to hire staff with new skills, 40 % planning to reduce staff as their skills become less relevant, and 50 % planning to transition staff from declining to growing roles." This development fosters increasing polarization of skills and income.

The World Economic Forum (2025: 6) expects a massive transformation in the skills that will be needed in the future, to which companies are called upon to respond. "On average, workers can expect that two-fifths (39 %) of their existing skill sets will be transformed or become outdated over the 2025–2030 period. However, this measure of 'skill instability' has slowed compared to previous editions of the report, from 44 % in 2023 and a high point of 57 % in 2020 in the wake of the pandemic. This finding could potentially be due to an increasing share of workers (50 %) having completed training, reskilling or upskilling measures, compared to 41 % in the report's 2023 edition."

However, Pfeiffer (2017) notes, a few years earlier and with a focus on the shop floor, a development that underpins the increasing importance of skilled workers in maintaining complex production processes in highly digitized production environments. The higher complexity of work tends to increase the importance of non-routine activities in highly automated production processes and requires a subjectification of workflows through holistic perception, explorative and dialogical approaches, intuition and empathic attitudes. Depending on the form of information processing and the resulting autonomy of production systems, skilled work is being upgraded rather than downgraded (cf. Becker et al. 2022b; cf. Bolwin et al. 2024). This statement is confirmed by the results of the bayme vbm study (2016) and supported by the EVA-METAL AND ELECTRICAL study, which analyzes developments in Germany (Becker et al. 2022; Becker et al. 2022b). A comprehensive view of the developments and effects of digitization is very important in any case, because, for example, when it comes to the application of Industry 4.0, it is fair to speak of a production paradigm. This is because, on the one hand, intelligent factories are developing and, on the other hand, production and logistics are global processes interconnected via the Internet. This enables a material flow that can be optimized and networked to an extent previously unknown. In many industrialized countries this development is regarded as part of the fourth wave of industrialization, which is commonly referred to as the "intelligent factory" or "smart factory" (cf. Nidhya et al. 2025).[1] The "smart factory" concept symbolizes a new wave of efficiency and advancement.

3 Concept of the Study

This article takes a closer look at the question of how the implemented concept of Industry 4.0 affects the need for qualification and competence at shopfloor level, what effects they trigger and what obstacles exist in their implementation. Beyond an evaluation of the current situation of changes of work, it also takes a look at the future and examines the extent to which there is a need for further development of occupations and which recommendations for action are available for designing and shaping the qualification and competence development processes in the metal and electrical industry of Germany. The basis for the explanations is work-related surveys that the authors conducted with a research group with representatives from the occupational science research and the Institute of the German Economy (IW). The complete results are documented in the EVA-M + E-study (cf. Becker et al. 2022).

A qualitative, occupational-scientific set of instruments and a quantitative company survey were used to answer the research questions of the study. The research design was geared towards identifying influences and changes on the shop

1 In the literature this new approach with smart factories is also understood as a new paradigm shift which represents Industry 5.0. The authors of this article understand this step of integration of robotics, AI, IoT, and big data to enhance machines and machine-human collaboration as a step already relevant in Industry 4.0.

floor by the actors involved, to be able to derive conclusions and recommendations for the future design of occupational profiles and training concepts.

A company survey was conducted to determine the state of implementation of the modernization of metal and electrical occupations. A total of 1,042 companies took part in the online survey. The research-based survey comprised 17 expert discussions with key individuals in the metal and electrical sector, 15 case studies with a total of 68 interviewees in selected companies of all sizes in Germany, and two expert workshops with a total of 31 participants to validate the research results of all sizes in Germany, and two expert workshops with a total of 31 participants to validate the research results.

3.1 Research Questions

The next two paragraphs discuss the research design, but do not describe all the details, as the article focuses primarily on presenting the results and how they can be used to further shape occupational profiles in the context of advancing digitalization in companies.

The studies examined the following questions in more detail:

1. What stage of development have companies currently reached in implementing Industry 4.0?
2. What are the key challenges facing skilled labor as a result of the digital transformation and which demands are being placed on skilled workers in networked production systems? Which professional competences of skilled workers result from this?
3. Do job profiles need to be changed/further developed in order to meet the requirements of a digitalized working world or will they become superfluous?

3.2 Research/Development Method, Approach and Implementation

The study was designed as a multi-stage process and was intended to provide answers to the research question and data for a discussion on the future development of selected industrial-technical occupations. It examined whether it is sufficient to respond to the consequences of digitalization with system-compliant answers, as has been the primary approach so far, or whether completely different design models for technical education and training occupations make sense. It also should be clarified why vocational learning will become more and more relevant because social and company-specific conditions for education and work are changing significantly.

The 15 case studies were conducted in selected innovative companies. Some of the companies are pioneers in the implementation of Industry 4.0. Companies that had not yet progressed very far with implementation of Industry 4.0 were also considered. The previous experiences in the design of the occupational profile position, such as the changed qualification requirements and demand due to the networked work systems in production, were recorded.

The companies for the case studies were selected and acquired in cooperation with the client and its regional member associations, representatives of trade unions and experts of the field. Several selection criteria were used, such as size, regional location, industry, orientation towards production areas and economic sectors, breadth and specialization of industrial-technical employment, training and innovative digitalization concepts. The selected companies should make it possible to draw a "picture" of the requirements of the metal and electrical industry that provides information about the company requirements due to digitalization in Germany.

The quantitative company survey with $N = 1{,}042$ companies made it possible to show the implementation status of the modernized training regulations for the metal and electrical occupations across the board in a reliable and clear manner, while the qualitative methods (case studies, expert discussions and expert workshops) provided a more in-depth insight into the practical side of training and helped to interpret the data obtained quantitatively. Both methods offer advantages that can be combined to provide a good overall picture. The data from the quantitative company survey is representative, i.e. the results are representative of all companies in Germany with at least one employee subject to social security contributions; the qualitative studies ensure validity in terms of content.

The expert interviews ($N = 22$ experts) required access to key individuals with a high level of expertise and experience regarding changes in the world of work in the metal and electrical industry and the skills requirements resulting from digitalization. Two researchers were involved in the expert interviews. One person had to have in-depth knowledge of the implementation of Industry 4.0, and the other had to be able to moderate an expert discussion in a balanced manner and with a high level of depth in the questions asked.

The aim of the two concluding expert workshops of the study with a total of 31 participants was to make the expertise of experts and key individuals in the metal and electrical industry (e.g. decision-makers from associations, science, companies and vocational training) available for the purpose of substantiating the findings of the previous research phases as far as possible, and thus to validate the results of the individual research phases.

4 Changing Demand on Skilled Workers – Macro Level

4.1 Overall Requirements on the Shop Floor

An analysis of the world of work and the existing qualification structures make it clear that employees at all levels of qualification are consistently dealing with digitally permeated work. In the companies considered, heterogeneous teams of (skilled) workers, engineers, IT specialists and work planners are needed to organize complex tasks such as commissioning, parameterization, multiple machine operation and other production and work processes. These teams are increasingly confronted with undefined amounts of data due to specific operational requirements, as in the case of a customer placing an order, as the example from a case study shows: *“In order to extract the necessary production information from this (from the data volumes, editor’s note), both academically trained and professionally qualified persons are necessary because the data show a very different character.”* (cf. case study).

Increasing automation in production is leading to a change in the generic tasks of skilled workers: they must perform their tasks with digitized tools, operate the production facilities via human-machine interfaces and develop their professionalism with the help of digitized media, control elements and cooperative work structures. There is no fundamental shift in the focus of their tasks: construction mechanics still must produce metal structures using welding processes, cutting machine operators still have to produce components using cutting processes, and electronics engineers for industrial engineering are still responsible for the electrical wiring of machines and systems. However, digitalized tools, methods and means of production are used in almost all tasks and production processes, and these require corresponding to knowledge of information technology. To the extent that they are involved in production and manufacturing processes, skilled workers require digital skills across the board, in addition to technical, social and personal skills that are geared towards specific production and maintenance tasks. The ability to apply these skills to master industrial mechatronics in all its aspects is one of the key areas of activity for skilled workers.

The theory of disruption, as a rapid and drastic development to which companies are subject due to the impact of digitalization, is not confirmed. Rather, the digital transformation in the metal and electrical industry is a continuous development process towards the further modernization of production with digital instruments. This is usually preceded by a process of optimizing the organizational structure and work organization in the companies. The development stages are planned carefully and rather cautiously. Nevertheless, they often have a major impact on the workforce because it is clear that the companies are embracing digitalization and implementing it. Companies are pursuing a variety of approaches, moving ahead at different speeds and using different types of software, systems and process steps.

All case studies highlighted the growing importance of electrical engineering and information technology for work in the metal and electrical industry. On the one hand, it is important that skilled workers on the shop floor be confronted with technological content from electrical and mechanical engineering that is integrated and kept in operation by software. On the other hand, when it comes to operation, maintenance, diagnosis and troubleshooting, it is essential that skilled workers have the necessary practical knowledge and skills. It is also clear that those training occupations in which these domains have a "production-related" significance are preferred. This means that companies are not relying on increasing training in electrical occupations or even information technology occupations for digitalization, as can also be seen from the development of electrical engineering occupations over the last 10 years. Those electronics technicians are chosen that can be trained and later employed with a close connection to production, in particular, electronics technicians for industrial engineering and also electronics technicians for automation technology. The latter, however, with a lower increase than originally expected in view of the developments in digitalization. The case studies show a tendency to incorporate necessary electrical and IT content into existing occupations – in particular, the electrician or the electrician for defined industrial tasks. In the last 5 years, the electrician training element has been offered either in-house or in collaboration with chambers of industry and commerce as an additional qualification for certification. One initiative by an automotive manufacturer, in which IT specialists in the field of system integration graduated with the additional qualification of an electrician for a fixed period of time for the first time in 2018, was particularly effective in terms of publicity (see case study).

Another example makes the nature of the integration of electrical and IT content into existing training occupations even clearer. In one case, a complex robotic welding application was implemented in production. One of the main requirements for the application was that construction mechanics must be able to operate the complex system to achieve flawless production results. The welding system and, in particular, the software required for it, were selected based on this requirement. However, there was no reorientation towards electrical engineering or IT occupations: "The software must be designed so that workers can use it, the welding process must be supported, the know-how for welding must be mapped there" (case study) by the skilled worker.

Examples such as these support the theory that a new trend is emerging for the metal and electrical occupations, which is expressed in the fact that the software to be used, or more generally digitalization, is to be thought of in terms of production (or more generally, in terms of work processes). While the trend in the first 5 years of the Industry 4.0 era was still characterized by the fact that the handling of data and software in the metal and electrical occupations developed into a new core competence that is still necessary today, “thinking in terms of software” (cf. bayme vbm studie 2016; Spöttl and Windelband 2016). It is now becoming apparent that companies require electric and IT skills and competences for operational tasks for all skilled workers and particularly for metal technology occupations. They no longer appear as separate competence requirements in connection with electrical engineering or information technology tasks, but as a standard for tasks in the generic fields of action of Industry 4.0. This orientation of the profiles differs considerably from traditional structures. Two central consequences of this development are as follows.

1. Training is less and less following the logic of the structures laid down in the training regulations. Despite the structural model of core and specialized qualifications (integrated qualifications), there is a strong separation of basic and specialized training, as well as content delivery structured by topics rather than by processes.
2. There is an increased choice of training occupations that can provide qualifications for digitized work processes – in particular, training as a mechatronics engineer and as an IT specialist at a skilled worker level.

In some companies, mechatronics technicians have (at least temporarily) pushed back or even completely replaced training for industrial mechanics (identified in four case studies). In particular, training for industrial mechanics appears to be decreasingly suitable for maintenance tasks in production, at least when the requirements of the training regulations are strictly adhered to and not interpreted flexibly enough. The tasks in maintenance are increasingly characterized by the penetration of digitalized tools. This penetration is associated with the adoption of “classic” tasks for maintaining production, such as replenishing parts or cleaning and maintaining production facilities: “In the past, 10 employees were needed for a production function, eight of them as parts inserters and two as line operators. Today, fewer employees are generally needed than in the past, and the majority are technologists who must have knowledge ranging from robot programming to maintenance tasks (including electrical engineering/automation). Only two employees are needed for parts insertion (parts inserters).” (Case study).

Depending on the importance of the automation solutions used, these tasks are increasingly being performed by mechatronics technicians and electricians rather than industrial mechanics.

These developments are accompanied by the increasing use of IT specialists in production-related areas. This also leads to an increase in the importance of training in information technology. Here, too, however, companies place a high value on "production-related" training. This means that when training IT specialists in the sought-after fields of application development, system integration or digital networking, for example, the production-related perspective should not be dominated by information technology, but rather by the production-related perspective.

4.2 Digitalization Tasks in the Companies – Operational Level

One of the key questions is whether digital transformation is visible in the companies. Based on the qualitative studies, this can be clearly affirmed. Four overarching developments can be identified in the empirical studies, which focus on different directions. The four types of companies are described and characterized below. Figure 2 summarizes the findings. It clearly shows that there is no "streamlined" development of one type of company or another. Rather, there are stages of development and reorganization that are deeply influenced by the existing machinery, with different machines of different ages. In concrete terms, this can mean for a company that a particularly suitable production line is converted to type 4, whereas other production lines – especially those using older machines – continue to work with traditional machines and processes. Types 1 and 4 can therefore coexist within the same company. This results in a highly heterogeneous machine park within a company. Long conversion times to Industry 4.0 are the consequence of such developments.

Character	Change in Production & Manufacturing Structures	Development Status
Type 1	Production and manufacturing structures unchanged	Careful optimization of organizational processes (oriented on lean production)
Type 2	Reorganization of production and manufacturing processes	Organization of data acquisition, Reorganization of individual machines towards production centers
Type 3	Structuring process sequences using digital data (analysis) and networked tools and software systems	Systematic optimization of processes through the implementation of software-controlled production units within the concept of Industry 4.0
Type 4	Networking of production plants and coupling of manufacturing systems to form cyber-physical units	Establishment of Industry 4.0 concepts and control of process sequences using standardized production data

Figure 2: Company types according to the degree of restructuring. Source: own presentation.

4.2.1 Characteristic of Type 1

The production and manufacturing structures in companies are unchanged from the 1980s and 1990s and only careful optimization of work organization and operational processes are taking place (2 cases), oriented in lean production.

4.2.2 Characteristic of Type 2

Companies focus on the manufacture of “intelligent products”. These companies place less emphasis on particularly automating manufacturing processes and reorganizing them according to the ideas of Industry 4.0. They concentrate on manufacturing products for special tasks and designing them particularly with the needs of the client in mind. Advanced software solutions are used for this. However, in most cases, this involves the manufacture of individual parts (4 cases).

Companies of types 1 and 2 have taken few or no steps to follow the Industry 4.0 concept. They maintain their traditional, mostly successful production structures.

4.2.3 Characteristic of Type 3

Companies are changing their organizational structures in such a way that the hierarchy created by ERP, MES and SCADA is becoming flatter. This goes hand in hand with the conversion of production lines, up to and including the almost complete networking of production processes. Modern technologies such as collaborative robots (cobots), learning machine controls, additive manufacturing systems, quality assurance using big data are used for this (6 cases).

4.2.4 Characteristic of Type 4

Companies are working to establish a new manufacturing philosophy as part of the digital transformation process. Individual departments are deliberately used to drive the conversion, working groups are put together, or digitalization teams (staffed with occupations that do not necessarily come from the occupational field of electrical engineering or information technology) are initiated to advance the digitalization process. The initiatives include reorganization processes (3 cases).

Companies of types 3 and 4 establish Industry 4.0 concepts by breaking away from traditional corporate structures or by setting up completely new manufacturing units.

The four stages of development can be transferred to four company types that are characteristic of the status of digital transformation in the metal and electrical industry (see Figure 2). It is obvious that the characterization of the company types is an ideal-typical representation and that in reality, hybrid forms often occur. In principle, the companies are currently developing with a high degree of dynamism. The increased use of data and digital tools, as well as other factors such as an improved order situation at the end of the coronavirus restrictions or a stronger focus on more sustainable production, is playing a major role here.

Regardless of the different directions of development, all companies that are driving digital transformation forward have in common the fact that they are proceeding very carefully. The top priority is always to avoid disrupting production. This means that the "degree of intensification of digital applications" varies in its level of advancement, because conversion measures are primarily driven forward in processes that build on each other. This iterative character can be the consciously cautious implementation of Industry 4.0 approaches in the entire production, as well as the conversion of only one production line or both together.

5 Key Research Findings

5.1 Four out of Ten Metal and Electrical Companies Have Adapted Their Training Content to Digitalization in the Last Five Years

Based on different levels of knowledge about the status of digitalization in metal and electrical training, 42.0 % of companies that provide training in at least one metal and electrical occupation have already adapted their training content to the course of digitalization. More than half (52.2 %) of companies have reacted to digitalization. Among higher digitalized companies, proportionally more companies have revised their training content than in smaller or less digitalized companies (cf. Becker et al. 2022a; Becker et al. 2022b).

5.2 Desire for Fragmented Innovations

Above all, the companies are realizing that the skills needed in the context of digitization are better integrated into the training rather than being taught in isolation. In in-company training practice they can implement this integrative approach to some extent, but this requires a conceptual effort to adapt to the training. The case studies show that despite awareness of the modernization or the implementation aids offered, it is almost impossible to successfully train topics related to digitalization because the training structures for this are lacking and because the training content is overloaded (ibid.).

In the end, the right topics are addressed, but as additional training content – according to the trainers – they are hardly suitable and tend to bypass the requirements of company work practice. Therefore, the adjustments and, above all, the new qualifications and competences are predominantly seen as elements for promoting high-performing trainees or there is a call for cooperation – especially with the vocational school – that can provide the additional training required.

5.3 Additional Qualifications for Training Have Not Proven Themselves and Are Hardly Used

The introduction of additional qualifications for the metal and electrical professions is not taking place to any significant extent in practice. Surveys show that at the end of 2022, 4 out of 10 industrial companies that provided training in metal and electrical occupations (39.1 %) offered additional qualifications. Among companies that are at least roughly familiar with the additional qualifications for the metal and electrical occupations, this share is just under three quarters (73.1 %). However, almost half (46.5 %) of the industrial companies were not yet familiar with the additional qualifications at the end of 2022 (cf. Becker et al. 2022).

The implementation of the additional qualifications is not successful, and the offer of certification combined with an examination has so far been virtually unused. The examination statistics show that additional qualifications account for a very small proportion of all final examinations in the metal and electrical occupations, at around one percent (cf. Zinke 2019). Companies see the high costs of organizing the examination, the costs, the low level of awareness, especially among small companies, the fact that the content is rarely taught separately (with the exception of additive manufacturing and programming) and the current overload in the metal and electrical occupations as the causes. However, most companies consider the content and orientation of the additional qualifications to be appropriate. That is why some of them implement them within the training without an official qualification. These results are consistent with the experiences of the project "Evaluation of the 2018 Amendment to the Metal and Electrical Occupations" at the Federal Institute for Vocational Education and Training. Here, too, the content of the additional qualifications is viewed positively for use in companies, even though their testability was and is considered not to be promising (cf. BIBB 2021).

5.4 The Metal and Electrical Training Occupations Are Overloaded in Terms of Content and Should Be "Streamlined"

The overload of current training occupations was clearly described as a problem in all interviews. New requirements are constantly being added, but there is no "streamlining" of the regulations. However, the interviewees disagreed as to what content could really be dropped from the respective training occupations. Although basic training in the metal and electrical professions should not be dispensed with, there was a clear call for a more process-oriented approach that is geared towards the requirements of the professional world of work. Basic training that is both mechatronic and production-oriented is a necessary objective for all training occupations, without which the overloading of the occupational profiles can hardly be reduced.

5.5 Training Structures Need to Be Rethought

The training departments of large companies are often still dominated by traditional training workshops, often with little concrete reference to work processes. In most of the cases studied, a paradigm shift could not be identified either in the equipment or in the qualification of the training personnel, with the result that a noticeable gap is emerging between training departments and company requirements. In some companies, changes could be seen with a process-related, project-oriented and in some cases cross-occupational design of training, but the discrepancy between the requirements of the world of work and training is still far too great. The training structures are predominantly structured according to the traditional training areas of the metal, electrical and IT professions and also according to the equally traditional structures of training content such as manual and CNC-supported machining, assembly, control technology, basic electrical circuits, programming, etc., instead of focusing on production-oriented tasks.

5.6 Vocational Schools Are Clearly Underestimated in Their Role and Importance in Managing and Shaping the Digital Transformation

Vocational schools are not formally involved in the implementation of new digital priorities. However, the quantitative and qualitative results show that some companies are sending a clear signal that vocational schools should be more involved in the new training content of the digital transformation. Companies are calling for involvement, especially for future topics and for mastering the knowledge-intensive challenges of digitalization, as part of dual training.

5.7 Innovative Design of Professions and Job Profiles

The expert interviews and case studies highlighted an "innovative gap" in the design of training among large, medium-sized and small companies. According to experts, many small and medium-sized companies are struggling to deal with the changes brought about by digitalization. This situation is exacerbated by regional differences (see expert workshop). Larger companies, on the other hand, want to drive innovation in production and training at the same time. This gap between small and larger companies has led to higher innovation requirements being postponed in the design of job profiles in earlier amendment phases. "For large companies that are interested in innovative training, the consequence of this was that they had to design training in such a way that they went well beyond the standard requirements." (statement of a training director). In many cases, the innovative gap outlined above is exacerbated by vocational schools when they are no longer able to teach the necessary technical skills due to a lack of qualified staff (several experts).

The question arises as to what significance innovative occupational profiles have if both SMEs and vocational schools are unable to implement them. One expert summarized the current situation in two theses (see expert):

(1) "The orientation of occupational profiles towards medium-sized and small companies contributes to cementing the status quo and preventing innovation!"

(2) "Levelling down technologically driven occupational profiles does not provide a challenge for innovation in training!"

The question is how this situation can be overcome. If it is assumed that a certain level of innovation and design competence is to be promoted in all participating companies with the help of training in order to successfully "transport" the digital transformation from training to work practice, then this requires first and foremost the design of innovative professions and demanding occupational profiles. The consequence of this objective should then be to massively promote and support their implementation. This means that vocational schools in particular but also training centers and training personnel (see expert), must be intensively qualified for this implementation task. Teachers and trainers must be qualified in a quality-oriented manner, both professionally and didactically and methodically, equipped with the necessary skills and enabled to implement innovative job profiles. The equipment at vocational schools must be thoroughly modernized and geared towards digitalization. This "thoroughness" must also be achieved across the board, as the learning factories and competence centers that have already been set up are not able to ensure a broad-based innovation boost that goes beyond the model character (cf. Windelband 2023). It is also no longer enough for vocational schools to simply see themselves as partners in training without playing a creative role. Vocational schools, training centers, companies, social partners and the responsible ministries should initiate a participatory process (see expert) that ensures the innovative implementation of modernized occupations and job profiles. Vocational schools and in-company training must be closely interlinked in this process, and vocational schools must establish themselves as a competent place of learning that can provide targeted support for in-company training.

6 Conclusions

The results show that the developments in the companies as a whole and in training in particular paint a wide-ranging and thoroughly heterogeneous picture in the context of digital transformation. Development steps towards digital transformation have been initiated in almost all of the surveyed companies. The speed and depth of the measures differ from company to company. It can be seen across the board that skills are required for the generic but digitalized fields of activity, i.e. skills for production, manufacturing, maintenance and the creation of metal designs in production, plant engineering or machine tool construction.

With regard to the modernization of training occupations, the following can be stated based on the surveys: "Detailed knowledge of the modernization of training regulations and their implementation is still very much in need of improvement in companies. After all, according to the results of the representative survey in 2022, a good half of metal and electrical companies are familiar with the new occupational profile and the additional qualifications in detail or at least in broad outline. Larger companies are more familiar with the modernization of the training regulations and have already dealt with them in detail more often than smaller companies" (cf. Becker et al. 2022). The data available from the nationwide statistics shows that additional qualifications are of very little importance as long as they are separate from the curriculum and initial standard training. Although the topics of the additional qualifications (e.g. additive manufacturing, programming, digital networking, IT security, system integration, process integration, IT-supported plant modification) are considered to be relevant in terms of content for training practice, companies expect that topics currently recognized as additional qualifications will become part of the core curriculum of initial training. In terms of content, additive manufacturing and programming are still the most frequently implemented and tested additional qualifications.

The results of the survey indicate that no fundamental shift in the focus of work tasks has yet been identified. However, digitalized tools, methods and production equipment are used in almost all work tasks and production processes, which require corresponding IT skills. Skilled workers need skills that are consistently mechatronic in nature and linked to specific professional tasks. Professional skills for mastering all aspects of industrial mechatronics are among the central fields of activity for skilled workers (ibid.).

In order to further advance the digital transformation, it would therefore be helpful to consider the importance of digitalization for initial and further training as a cross-sectional technology more systematically and to link it to corporate strategies. To this end, the existing training occupations in the metal and electrical industry should be realigned in terms of mechatronics-oriented basic and specialist training without overloading them with content. The newer digitalization approaches (teaching methods in robotics, no-code and low-code programming approaches, etc.) offer as yet untapped potential for vocational training in particular.

Empirical findings also suggest that technological convergence can progress rapidly through digitalization, networking and virtualization. For occupational profiles, this probably means that the previous differentiation should be abandoned in favour of hybrid occupations (cf. Bosch 2025). For the metal and electrical sector, the authors propose a hybrid profile with the designation "*Industrial Mechatronics*" (Figure 3). This would combine the domains of several occupations to create a broader basic qualification for industrial specialists and enable specialization for various production tasks in a second step. This requires moving away from

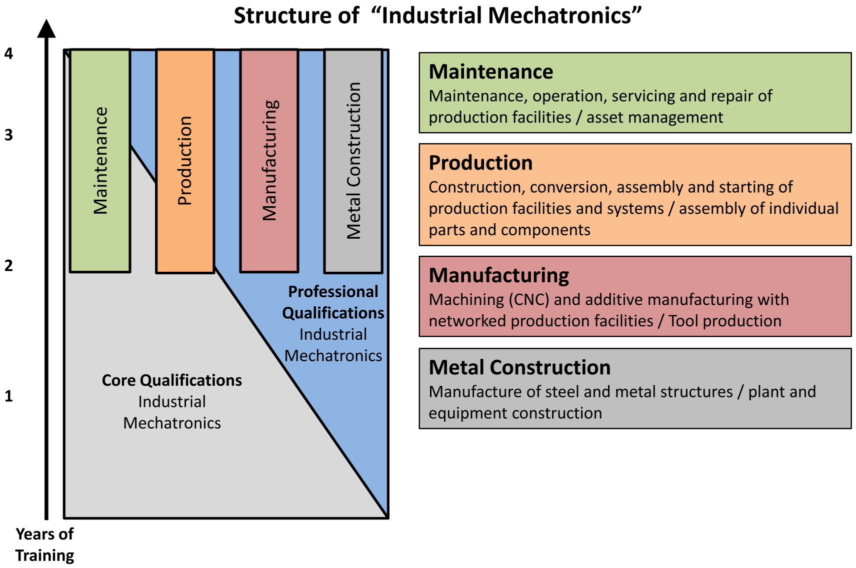

Figure 3: Hybrides occupational profile.

separating vocational training according to technological fields. In this case, the separation into metal technology, electrical engineering/electronics and information technology would have to be overcome. Differentiation and specializations would be developed in line with the different areas of activity in the companies. This would also lead to an increase in identity formation during training, because the demarcation lines between several occupations would be overcome. This can currently be seen, for example, in the training occupation of industrial mechanic, for which future designations such as "asset manager" are already being discussed and which is increasingly being replaced by mechatronics engineers (at vocational level) in the companies surveyed.

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Materials/records:

Expert workshops as part of the study.
Expert interviews as part of the study.
Case studies as part of the study.