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Concepts, Guidelines, Best-Practice Examples

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Preface

Today's Major Educational Challenges in the World

Economic growth and global welfare are challenged by a lack of well educated and suitably qualified workforce. The three major challenges encountered are:

- Insufficient availability of skilled and qualified workforces and engineers,
- A mismatch between qualification of the available workforce and the changes in industrial demands,
- Declining awareness of the importance of effective technical education over all hierarchical levels.

Production-related competencies and skills are and will remain an important compound of countries' economic development and growth as well as industries' long-term competitiveness. Good qualifications are also the decisive factor for prosperity and advancement on a personal level. Solutions must be quickly found for approaching the mismatch of institutional qualification programs and actual market requirements. On the one hand, the future workforce must be qualified for current employment opportunities, while on the other hand, today's generation needs to be enabled to keep up with competences required in the future.

Universities are often not fully aware of the challenges their students face in working life. Knowledge in basic engineering fields, like mechanics and thermodynamics, is still necessary but must be enhanced by process-oriented domains. In order to be optimally prepared for a career in industry, students

- have to understand the complexity of the systems and processes in a real workshop,
- must develop adopt the capability to improve the value stream with up-to-date methods,

- need to know the applications of digitization in the context of production and its improvement and be able to plan such systems, and
- have to develop more social and personal competencies like teambuilding and leadership.

Learning factories offer a promising environment to address the challenges mentioned above in education and training and also in research on process-oriented improvement in production. While numerous learning factories have been built in industry and academia in the last decade, a comprehensive scientific overview of the topic is still missing.

This book intends to close this gap by reviewing the current state of research and practice on the subject of learning factories. In addition, it gives the reader an overview of existing learning factories, their hardware, their didactic, and their operating concept.

We are convinced that learning factories can play an important role in the excellence of future generations of engineers and production employees.

Darmstadt, Germany

Eberhard Abele
Joachim Metternich
Michael Tisch

About This Book

"Learning Factories" according to Encyclopedia CIRP, see Abele, E. (2016). Learning Factory. *CIRP Encyclopedia of Production Engineering*.

"A Learning Factory in a narrow sense is a learning environment specified by

- **processes** that are *authentic*, *include multiple stations*, and comprise *technical* as well as *organizational* aspects,
- a **setting** that is *changeable* and resembles a *real value chain*,
- a *physical* **product** being manufactured, and
- a **didactical concept** that comprises *formal, informal and non-formal learning*, enabled by *own actions of the trainees* in an *on-site learning* approach.

Depending on the **purpose** of the Learning Factory, learning takes place through *teaching*, *training* and/or *research*. Consequently, learning outcomes may be *competency development* and/or *innovation*. An operating model ensuring the sustained operation of the Learning Factory is desirable.

In a broader sense, learning environments meeting the definition above but with

- a setting that resembles a *virtual* instead of a *physical value chain*, or
- a *service* product instead of a *physical* product, or
- a didactical concept based on *remote learning* instead of *on-site learning*

can also be considered as Learning Factories."

Contents

About the Authors

Prof. Dr.-Ing. Eberhard Abele was born in 1953 and studied mechanical engineering at the *Technische Hochschule Stuttgart*, Germany, where he received his diploma in 1977. Afterward, he was a research assistant and department manager at the Fraunhofer Institute for Production Technology and Automation, Stuttgart, (IPA). From 1983 to 1999, he held a leading position in the automotive supply industry as main department manager of manufacturing technology and factory manager with stations in Spain and France. The focus of his industrial activities was on automation, increase in productivity, and speeding up production. Since July 2000 he is leading the Institute of Production Management, Technology and Machine Tools (PTW) and contributed to more than 200 publications in the field of manufacturing organization, machine tool technology, and manufacturing processes.

The Process Learning Factory (CIP), which he initiated, has shown a novel path in the long-term qualification of university graduates and employees from companies in teaching, but also in further education in the field of production technology and lean management. He led the initiative *Produktionsforschung 2020* for the *Bundesministerium für Bildung und Forschung* (BMBF). He is the founder of the Initiative on European Learning Factories and chairman of the magazine *Werkstatt und Betrieb* of the Carl Hanser publisher.

He initiated the research project *eta-Fabrik* (learning factory for energy efficiency) with 35 partners with a total project sum of 16 million euros.

Since 2012 the PTW is managed together with Prof. Metternich.

Prof. Dr.-Ing. Joachim Metternich studied industrial engineering at the Technical University of Darmstadt and received his doctorate in 2001. After his time as assistant of the CEO of TRUMPF Werkzeugmaschinen GmbH, he headed a production group at Bosch Diesel s.r.o. in the Czech Republic. He then took over the responsibility for the worldwide lean production system of Knorr-Bremse SfS GmbH, a manufacturer of braking systems for rail vehicles. Since 2012 he has been one of the two directors of the Institute of Production Management, Technology and Machine Tools (PTW).

Dr.-Ing. Michael Tisch studied industrial engineering with a technical specialization in mechanical engineering at the Technical University of Darmstadt. Until July 2018 he worked as chief engineer at the Institute of Production Management, Technology and Machine Tools at the Technical University of Darmstadt. In his research, he deals with the competency-oriented learning factory design in the field of lean.

Chapter 1
Challenges for Future Production/Manufacturing

Education and training have numerous positive effects on the individuals, and the companies these individuals are working for as well as on society. If we bear this in mind, it is obvious that more high-quality education and training are beneficial to everyone (Fig. 1.1).

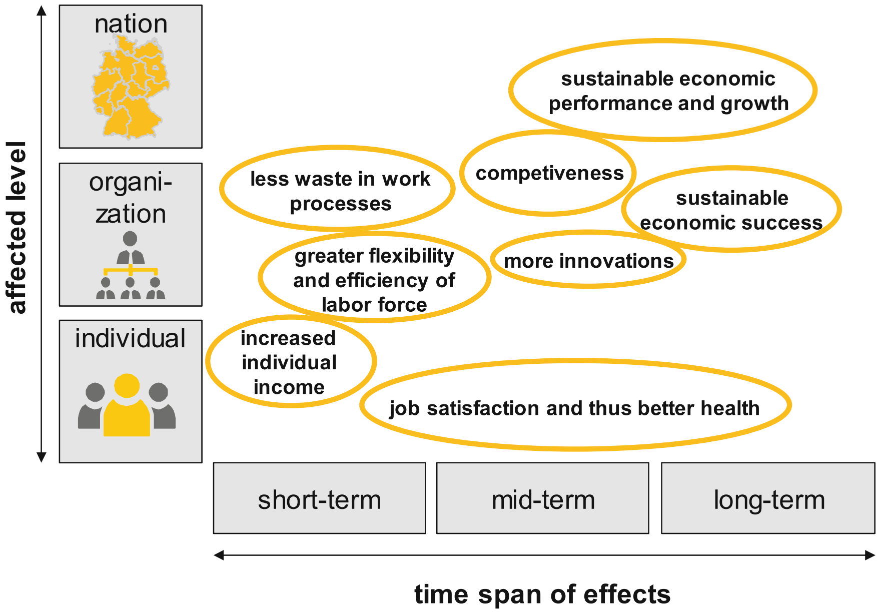


Fig. 1.1. Effects of education and training on national, organizational, and individual level

E. Abele et al., *Learning Factories*, https://doi.org/10.1007/978-3-319-92261-4_1

In economic terms, the general positive effects of educational quality on individual income, competitiveness of enterprises, and economic growth were shown.[1] It can be concluded that human capital is key to economic development.[2] On the personal level, incomes of individuals and cognitive skills are systematically related.[3]

Also for companies in the manufacturing sector in particular, the education and training play a crucial role. Today's and tomorrow's economic success of companies depend on the capability and the knowledge of engineers and managers.[4] It is mentioned that the lack of skills, e.g. entrepreneurial, managerial, or scientific management skills, greatly reduces the ability to innovate regarding fundamentally new products, process efficiency, productivity, and quality.[5] Studies forecast a significant shift in labor demand toward more knowledge- and competency-intensive jobs in the future.[6] For this reason, a larger number of specialists are needed, with gaps being expected in the future for certain professional functions and qualifications.[7] Positive effects of education for the recruitment of the new knowledge workers are also mentioned in this context.[8] In the literature of education controlling is stated that the return on training is almost always positive, can be very high, and can occur in many forms. Examples for the benefits induced by education are among others a greater level of value-adding activities, higher flexibility and a better innovation ability.[9]

In the long-term education and training are crucial for economic growth and the competitiveness of whole nations: "[…] a more skilled population – almost certainly including both a broadly educated population and a cadre of top performers – results in stronger economic performance for nations."[10]

"More and better education tends to shift comparative advantage away from primary production toward manufacturing and services, and thus to accelerate learning by doing and growth."[11]

Furthermore, for any nation, the industry sector is an important factor for the creation of wealth. For example, in Europe more than 26% of the value-added share in the non-financial business economy is accounted to the manufacturing sector.[12] Despite the widely propagated change from the industrial to the service and information society, the facts show production is still the backbone of the prosperity of

[1] See Gylfason (2001), Hanushek and Woessmann (2007), Barro (1996).
[2] Hanushek and Woessmann (2007).
[3] See Hanushek and Woessmann (2007).
[4] See O'Sullivan, Rolstadås, and Filos (2011).
[5] Tether, Mina, Consoli, and Gagliardi (2005).
[6] CEDEFOP (2010).
[7] See Vieweg (2011).
[8] See O'Sullivan et al. (2011).
[9] See Smith (2001).
[10] Hanushek and Woessmann (2007).
[11] Gylfason (2001).
[12] See Eurostat (2016).

the industrialized countries.[13] In Germany, over 8 million jobs are directly located in production areas.[14] In addition, approximately 6 million employees were allocated to the production-induced area of corporate services such as logistics and information technology.[15] This means 14 of in total 40 million employees in Germany are directly associated with the production sector. Some estimations conclude that in total 70% of jobs and 75% of the GDP in Europe are related to manufacturing.[16]

In order to obtain the importance of the sector in respective regions, excellent production processes are necessary to compete in the global race. Today, manufacturing is confronted with several megatrends and significant innovations, inter alia, regarding technologies, tools, and techniques. In this respect, we start with the question: What are the main drivers for the development of the production of the future? And based on this, continuing with the question: What particular competences do we need for the production of the future. This chapter therefore deals with the challenges for future production. In order to tackle those challenges properly, today's and future's engineers and blue-collar workers need the capability to learn and adjust to new situations—Chap. 2 deals with required competencies for future production. Chapter 3 addresses the ways that are available for competency development for production and concludes with the need for learning factories for manufacturing.

Learning factory design must pick up current and future developments in production. Those developments are accompanied by economic, ecologic, and social megatrends we currently recognize. Megatrends are seen as enormous economic, social, political, and technological changes with high probability that influence our lives for many years (7–10 or longer).[17] Although temporarily short-term developments may superimpose megatrends, in the longer term, they determine the direction of change regarding organizational, technological, and human-related issues.[18] These changes in production must be addressed with groundbreaking innovations regarding production processes, products, services, and technologies.[19] In Fig. 1.2 exemplarily an overview of the megatrends[20] can be found.

A loss of 20–25% of the production-related jobs is predicted in economies when companies do not adapt to these trends. These developments lead to a rapidly growing uncertainty and complexity in manufacturing companies, which will require new knowledge, skills, and competences. In addition, developed industries are under the pressure of an aging workforce, to secure their competitive advantage, the innovation of product and process must be supported by new approaches to develop

[13] Abele and Reinhart (2011).

[14] See DESTATIS (2016).

[15] See DESTATIS (2016).

[16] See O'Sullivan et al. (2011).

[17] Naisbitt (1982).

[18] See Abele and Reinhart (2011).

[19] See Grömling and Haß (2009).

[20] Identified by Abele and Reinhart (2011).

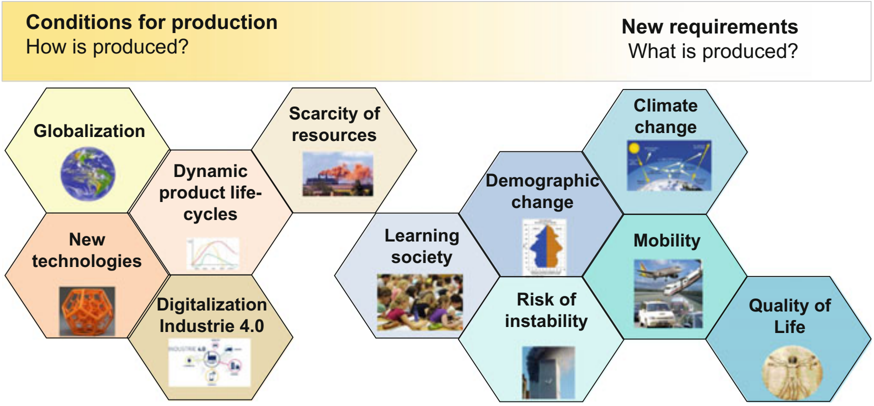


Fig. 1.2 Megatrends with crucial importance for production and products (Abele & Reinhart, 2011)

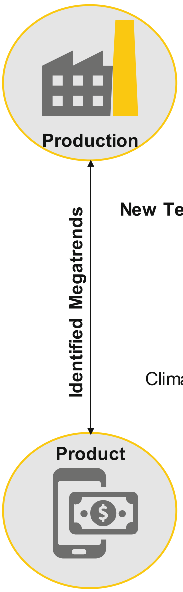
production-related competences at all hierarchical levels.[21] The recruitment and especially the development of competent employees are crucial competitive factors of companies that determine the success or failure. Figure 1.3 shows the result of a literature study looking at ten individual studies on the future of production.

In the overview, it is also shown whether the identified megatrends have an effect on the future design of the production processes or product characteristics.[22] The trends listed higher in the figure have a greater impact on the production, while the ones below have a corresponding effect on the product design. Globalization and thus an intensified competition, dynamic product life cycles, the emergence of new technologies, digitalization and networking, the scarcity of resources, the importance of knowledge, the risk of instability as well as demographic change are identified as the most important challenges for industrial production.[23] Figure 1.4 shows an overview of the structure of this chapter on the challenges for future production.

1.1 Globalization

The global integration of businesses, culture, politics, and other areas is referred to as globalization.[24] The main reasons for this development can be found in the progress of ICT, better quality of traffic technology, and the liberalization of world trade.[25]

[21] Abele and Reinhart (2011), Adolph, Tisch, and Metternich (2014).
[22] See also Abele and Reinhart (2011).
[23] See Adolph et al. (2014).
[24] Abele and Reinhart (2011).
[25] See Arndt (2008), Naisbitt (1982).



	Abele, Reinhart (2011)	Arndt (2008)	Graf (2000)	Grömling (2009)	Herrmann (2010)	Jovane, Westkämper (2009)	Krys (2011)	Schneidermann (2006)	Warnecke (1999)	Wartenberg, Haß (2005)
Globalization	●	●	●	●	●	●	●	○		●
Shortening of Product Life Cycles	●	●			○					
New Technologies Digitalization / Networking	●	○	●	●	●	○	●	●	●	●
Scarcity of Resources	●		●	●	●	●	●	○	○	
Knowledge Society	●		●	●	●	●	●		●	
Increasing Customer Demands		●			○					
Services in an Industrial Environment					●				●	●
Demografic Change	●			●	●	●	●			●
Risk of instability & Security	●			●	●			●		
Investment and Infrastructure				●	○	○				●
Climate Change / Environmental Degradation	●			●	●	●	●	○	●	
Mobility	●			○	●	●				
Welfare Orientation				●	●	●				
Market of the Future Quality of Life	●				○	●				

● Explicit mention of the megatrends
○ Implicit mention or used on the edge of a development

Fig. 1.3 Identified megatrends in literature shown in Adolph et al. (2014), based on Abele and Reinhart (2011), Arndt (2008), Graf (2000), Grömling and Haß (2009), Herrmann (2010), Jovane, Westkämper, and Williams (2009), Krys (2011), Warnecke (1999) und Wartenberg and Haß (2005)

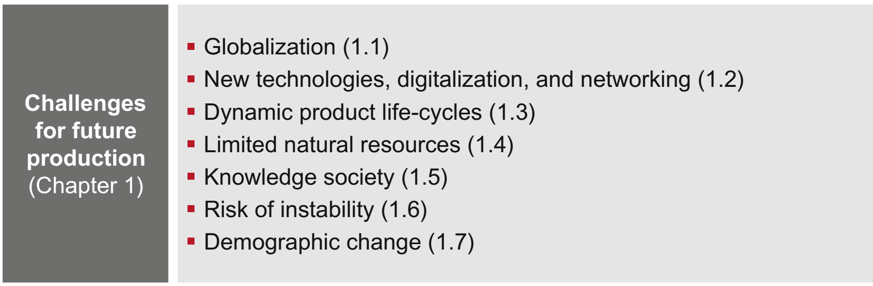


Fig. 1.4 Overview on the structure of this chapter

Although currently protectionist policies and a restriction of free trade seem to be gaining the upper hand, time will tell whether the long-term trends of globalization and liberalization are actually broken or will even be reversed, or whether only temporary phenomena can be observed. In the past, a successful export orientation enabled many European countries to benefit from the trend of global networks and thereby secure or even expand production and related jobs in their own country.[26] The example of German industry shows that production of high-quality goods in international networks has a positive effect on the national employment in industry, as long as the core production expertise will remain in the home country.[27] This preservation of jobs in the home country can only be realized with an educated and well-trained workforce. Furthermore, the globalization trend can also be perceived in international acquisitions of (mainly industrial) companies: The yearly number of acquisitions from China in Europe has risen by 48% from 2015 to 2016—and has multiplied more than sevenfold in the last ten years.[28] This phenomenon leads among others to the

- need for international cooperation,
- globally networked value chains that must be designed and managed, and
- a high demand for the worldwide standardization of production systems.

Figure 1.5 shows the number of acquisitions or investments of Chinese companies in Europe as well as a few prominent European companies acquisition China.

Consequently, in light of the megatrend globalization several challenges arise for industrial companies in high-wage countries:

- Achievement of leading productivity in international comparison,
- Availability of well-educated and excellent trained workforce; thinking globally, acting locally,
- Ensuring the highest quality of goods in the production network as a prerequisite,
- Achievement of high levels of changeability and flexibility of production systems.

In our discussion with Production and Human Resources Managers related to the megatrend globalization, it was often argued that future blue- and white-collar workers.

- Need possibilities to develop and improve their intercultural skills,
- Get earlier in touch with global procurement processes, and
- Have to opportunity to experience optimization and best practice examples of production processes, production systems, and value creation networks.

1.2 New Technologies, Digitalization, and Networking

Innovations are enabled by an increasing cooperation and integration of disciplines, since innovations often originate at interfaces of disciplines. For example, with the integration of first mechanics and electronics and subsequently with informatics,

[26] See Grömling and Haß (2009).

[27] Scherrer, Simons, and Westermann (1998).

[28] See Sun and Kron (2017).

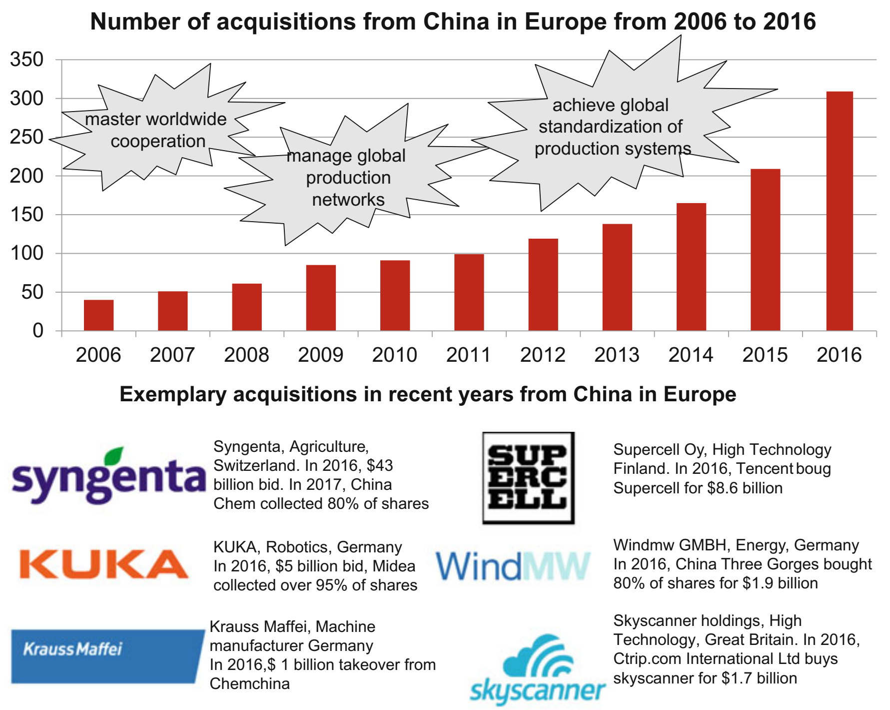


Fig. 1.5 Chinese acquisitions in Europe in recent years (will) lead to various challenges for production, data from Sun and Kron (2017)

innovative products and production processes are facilitated.[29] Most recently, the buzzword Industrie 4.0 (or also industrial Internet) falls into this category and has decisive influence on the way in which production processes are to be designed in the future. The Industrie 4.0 "project" envisions a factory with networked equipment, in which every product knows or even finds its way to finalization.[30] Consequently, the role of humans in production systems may shift if they are relieved of routine activities and on a broad data basis optimal decision making is enabled.

[29] Abele and Reinhart (2011).

[30] See Promotorengruppe Kommunikation der Forschungsunion Wirtschaft - Wissenschaft (2013).

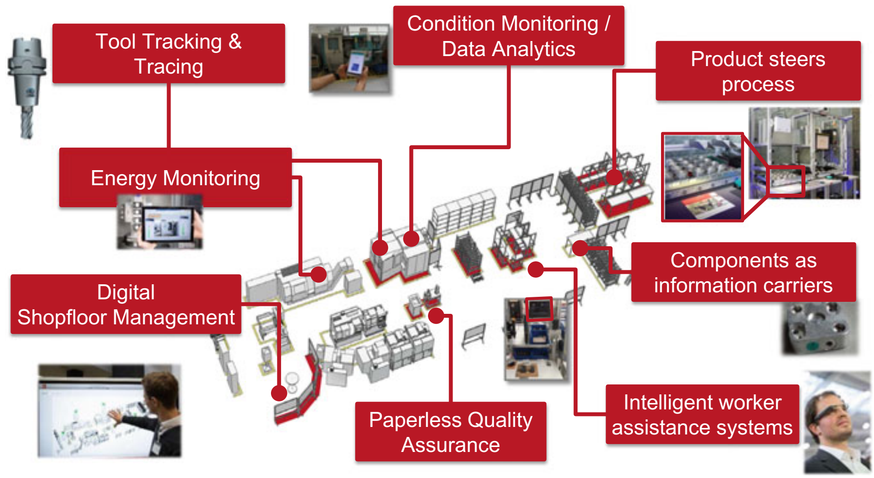


Fig. 1.6 Exemplary Industrie 4.0 concepts implemented in the Process Learning Factory CiP in Darmstadt

Figure 1.6 exemplarily shows some implemented Industrie 4.0 concepts and use cases in the Process Learning Factory CiP in Darmstadt:[31]

- Components as information carrier: In order to achieve efficient and future-oriented production in the sense of Industrie 4.0, the collection and the processing of the data that is generated during the value creation process are particularly important. In addition to the integration of necessary sensors into the production process, communication between all the systems and equipment involved is also necessary for the implementation of a media-free, digital and typically automatic data acquisition.
- Tool tracking and tracing: By integrating innovative sensor technology into the tool holder, the tool can be monitored and the entire tool circuit can be networked. The track and trace system on the control level makes it possible to optimize route planning, inventory management, procurement, storage location, and storage size actively.
- Condition and energy monitoring: With condition and energy monitoring, data from manufacturing machines can be used to access a real-time image of the quality or the energy consumption of the production process. The quality of the processing state here includes the control of product state, process state, and machine condition.
- Product steers process: The product variant is defined with a product configurator by the customer; the information is stored directly on the component. Before assembly, the component uses RFID to call a type-specific nonlinear assistant system for the respective operator, which allows the desired motor configuration

[31] A detailed description of the implemented use cases can be found in Abele et al. (2015) and PTW, TU Darmstadt (2017a).

to be built. Data generated during processing such as assembly and screw protocols is stored cloud-based and can be accessed by the RFID information. In this way, the data remains permanently available.

- Digital shop floor management: In the context of the networked factory, employees face complex IT systems and autonomously operating machines. Employees in this environment have to simultaneously act as a flexible and creative problem solver. An instrument for supporting employees in this process is shop floor management enabled by now available real-time data. This serves as a central communication and collaboration platform for the employees at the shop floor in their daily tasks.
- Digital twin: In order to obtain all relevant information about the process in real time at all times, a digital value stream image is used. In this, all relevant information flows are networked across the entire value stream. The user-friendly visualization and linking of these previously separately collected and used data provides the basis for the rapid detection of potentials for improvement.
- Paperless quality assurance: A paperless, reliable, and automated quality assurance system is demonstrated in the manual assembly of the pneumatic cylinder. An electronic screw station is not activated until the upstream quality control releases the component. The screw station selects the corresponding screw program based on the present variant, and a work instruction is displayed to the worker. During the assembly of the cylinder, additional process characteristics for quality detection, e.g. torque or yield points are assigned to the identification number of the pneumatic cylinder currently being processed. The continuity of the documentation accompanying the process of the product quality as well as the test results enables a holistic traceability on the product level.
- Intelligent worker assistance systems: Assembly information is created and made available interactively from the 3D-CAD system for the assembly of small batch sizes. Parts of the implementation are intelligent networking of all components of the assembly workplace as well as systems for visual support and control in the assembly process. A bidirectional information flow between the system and the employee is enabled.

Another important key technology is seen in the additive manufacturing. Using the additive manufacturing with metallic materials, new shapes and geometrical features can be fabricated on-demand and customized.[32] But those additive manufactured parts will not only affect the possibilities to design products but also the possibilities and requirements of respective manufacturing processes. Accordingly, processes starting from CAD data creation over preprocessing, the actual additive manufacturing process, and post-processing have to be developed and designed which requires technological innovations and a broad variety of new additive manufacturing competences in companies in order to fully integrate and use the potential of additive manufacturing. Figure 1.7 illustrates a typical additive manufacturing process chain that can be part of a learning factory for additive manufacturing.

[32] See Vayre, Vignat, and Villeneuve (2012), Huang, Liu, Mokasdar, and Hou (2013).

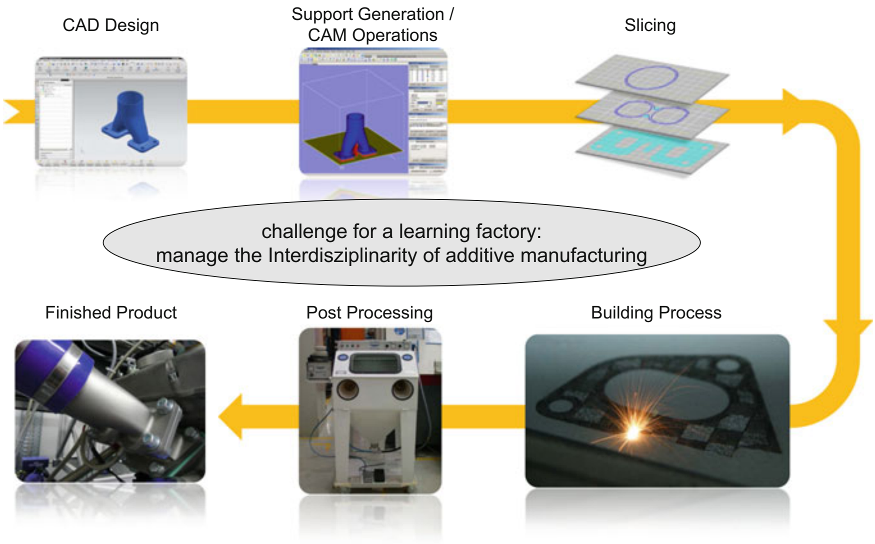


Fig. 1.7 Additive process chain changes the possibilities and requirements of manufacturing processes

Based on the mentioned new technologies for future production, the following challenges can be identified:

- Integration of innovative key technologies in production environments, e.g. additive production technologies,
- Digitalization and networking of existing production environments,
- Creation of simplified supply chains when powder or granulate replaces supplied parts,
- Consideration of adapted visions, principles, and methods in production systems.

Consequently, those challenges are related with a changing competency profile of today's and tomorrow's production workers and associated changing learning requirements:

- New competences and expertise for key technology-induced innovative products, processes, and production systems applying key technologies,
- Sound knowledge of visions, goals, and principles of production systems in general in order to overcome pure technology orientation and realistically assess the possibilities of new technologies in a benefit-oriented manner,
- Learning environments are needed in which blue- and white-collar production workers access and experience those key technologies like additive manufacturing and digitalization.

1.3 Dynamic Product Life Cycles

In the last decades, an increasing demand for customized products can be noticed which leads to shorter product life cycles reinforced by the technical advancements and the attempt to sell more products through more innovations in saturated markets. This means the time between two successive product generations is becoming shorter and shorter; average life cycles in the automotive industry in 1980 lasted approximately eight years, twenty years later the duration of life cycles is halved at four years. These developments lead to increasing demands with regard to changeability and adaptability of companies, their production systems, and their employees.[33] For the flexibility and the changeability of processes and organizations, it is argued that the investment in the lifelong competence development of the personnel is crucial[34].

In summary, by shorter cycles, it is possible to generate additional sales in mature markets with variations of products. A shorter time when a product is offered and declining sales of individual models are the results, i.e. individual models are produced in ever-smaller quantities. Consequently, the challenges and needs related to the capability of the workforce are:

- the risk of investments increases as a shorter amount of time is available to earn back invested capital.
- high demands on the ability to change and adapt of the whole company, the factories, and the employees.
- complex products raise the demands on the cognitive abilities of employees.
- more frequent production ramp-ups have to be mastered in a shorter amount of time; staff has to be prepared for those non-routine situations.
- higher demands on the flexibility of production plants and employees due to the individualization of products.
- suiting learning environments are needed that are able to map dynamic production systems.
- cost reduction effects resulting from learning curves based on repetitive activities are mitigated in these environments. Work-integrated learning methods to accelerate the learning curves are needed.

1.4 Limited Natural Resources

A shortage of resources is predicted in the coming years because of increased living standards, world population growth, and the partially irresponsible consumption of resources.[35] The publication of "The Limits of Growth" in 1972 launched a major controversy over how economies should grow and how they can grow sustainably in

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[33] See Abele and Reinhart (2011), Westkämper and Zahn (2008), Arndt (2013).

[34] See Wagner, Heinen, Regber, and Nyhuis (2010), Adolph et al. (2014).

[35] Abele and Reinhart (2011).

the end.[36] The study, commissioned by the Club of Rome, predicts insurmountable and inevitable problems with unchanged economic development within few decades. From today's perspective, those prognoses have to be questioned knowing that the development of mining technology kept pace with the consumption of static resource range.[37] But to rely only on a technological advancement of the extraction, technology seems risky. In order not to impose a high raw material prices in the long term, manufacturing companies need not only innovations in mining technology, but above all resource-efficient production processes and the use of alternative materials for the produced goods.[38] Here an interdisciplinary cooperation between materials science and production technological research is required.[39] A future-oriented curriculum as well as a learning factory has to address four main questions:

- Which natural resources (energy, materials) have to be replaced in the coming years?
- Which alternative solutions are already today available?
- What are the challenges in product development and production engineering for the shift of resources?
- How can the new solutions be justified (economically, ecologically)?

In addition, over the past years, the issue regarding energy efficiency gained major interest from society, politics, and economy. Especially, interdisciplinary energy efficiency aspects have not yet been considered in industry, research, and education. Furthermore, until today, the energy efficiency is not yet integrated into engineering education. For example, aim of the research project ETA-Factory[40] was to construct a model factory, which integrates various interdisciplinary approaches reducing energy consumption and CO_2 emissions of production processes in industry, see Best Practice Example 6. Figure 1.8 shows an overview of the targets and the solution approaches to more energy-efficient production processes in course of the project.

Furthermore, in light of the energy transition and the associated challenge of a high proportion of wind and solar power, the generation and consumption of electrical energy must be timely coordinated with each other. This can be done on the one hand with innovative power storages, or on the other hand, with a so-called demand-side management (DSM), i.e. more flexible power consumption. For this, innovative and adapted technologies are needed for future industrial processes.[41]

In general, the efficient and flexible use of energy and non-energy raw materials in along with the complete product life cycle must be taken into consideration for economic and ecological reasons.[42]

[36] Meadows (1972).

[37] See Frondel (2008).

[38] See Abele and Reinhart (2011), Herrmann (2010).

[39] Abele and Reinhart (2011).

[40] See PTW, TU Darmstadt (2017b).

[41] See BMBF (2018).

[42] See Herrmann (2010), Bullinger, Jürgens, Eversheim, and Haasis (2013).

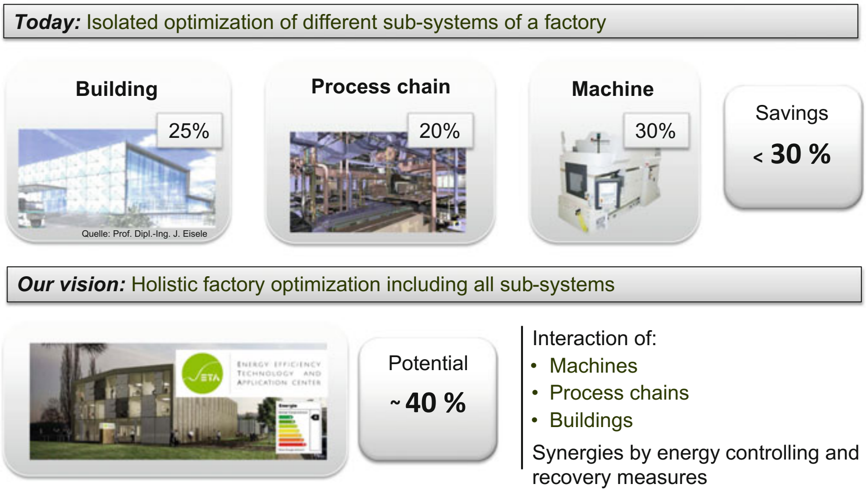

Fig. 1.8 Aim of the research project ETA-Factory (PTW, TU Darmstadt, 2017b)

The following challenges can be identified for future production:

- Energy and non-energy resource efficiency along the complete product life cycle,
- Innovative power storages and flexibility in the energy consumption of industrial processes,
- Alternative materials and production processes for innovative products.

Interviewed experts identify among others the following necessities for education, training, and research in the field of limited natural resources:

- Research environments are needed in which innovative technologies and processes for the efficient and flexible use of energy can be developed, tested, and transferred to industry.
- Sensitization for the topics resource and energy efficiency via integration of those topics in the curricula.
- Learning environments that are able to make energy-efficient production tangible, which is a challenge since energy flows are mostly not observable by the eye.
- Interdisciplinary education and training efforts in dedicated energy and resource-oriented programs.

1.5 Knowledge Society

In the twenty-first century, in many branches of Western industry the activities of workers are knowledge-based largely. Work processes are in those cases no longer highly dependent on manual skills, but on the knowledge of individuals and the organizational knowledge of companies.[43] Consequently, knowledge and education are the key resources for social and economic advancement.[44] Particularly in countries with no or few mineral resources, knowledge and the resulting innovation factors are decisive for prosperity. It is not surprising in this context that the countries with a low raw material-dependent share of GDP are investing heavily in education—and, on this basis show the significantly higher GDP growth rates.[45] Better education is usually associated with wage increases, which in turn must be justified by productivity gains, which in turn are again based on better education and training of employees who design and execute processes. In particular, three drivers can be identified that increase the importance of production-related knowledge and education:[46]

- Production technologies, that are continuously improved, tend to get more complex at the same time. On a higher level, this leads to significantly more complex production systems.
- As shown in Sect. 1.3, product life cycles are getting shorter. Product- and technology-related knowledge is correspondingly faster outdated.
- The length of employees staying in one position or department is diminishing. Exemplarily, from 1980 to 2010 the average stay of a production planner in one position went down from eight to just four years (Fig. 1.9).

Under these new conditions, production-related competencies in various domains must be developed more quickly. The knowledge associated with these competencies must be constantly identified, internalized, and transferred. As the production systems become more complex, the development of competencies becomes more difficult and has to be done more quickly.[47] In the future, innovative learning ways as well as methods and tools for the management of the rapidly generated knowledge are necessary.[48] Blue-collar workers and engineers require innovative lifelong ways of learning to keep up with described dynamics.[49] In summary, the following challenges can be identified:

[43] See Bullinger, Spath, Warnecke, and Westkämper (2009).

[44] See Abele and Reinhart (2011).

[45] See Gylfason (2001).

[46] See Abele and Reinhart (2011), Chryssolouris, Mavrikios, and Mourtzis (2013).

[47] See Adolph et al. (2014).

[48] See Abele and Reinhart (2011).

[49] See Chryssolouris et al. (2013).

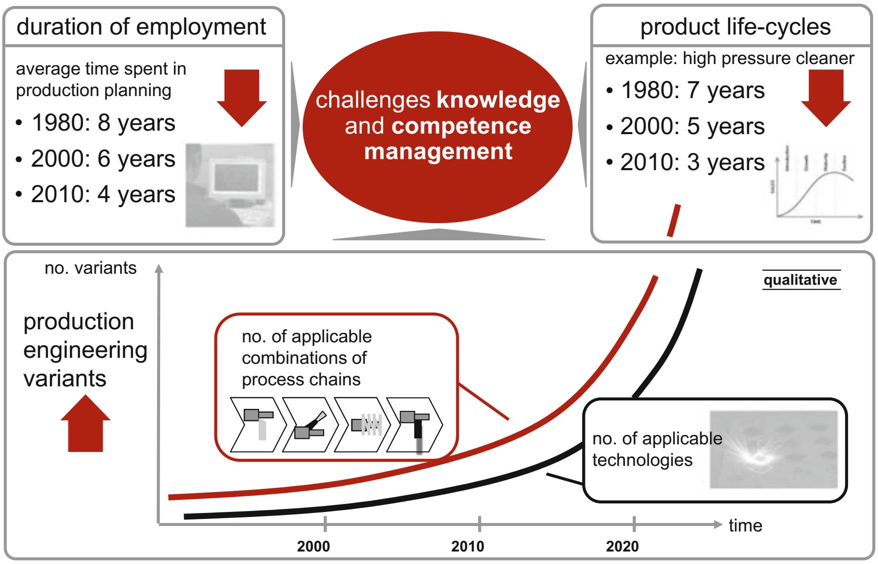

Fig. 1.9 Current challenges in production technology require efficient forms of knowledge and competence management, with slight changes according to Abele and Reinhart (2011)

- Establishment of learning organizations and work-integrated forms of learning in order to adapt on a corporate level to new situations and to preserve competitiveness,
- New ways of learning systems and methods used for education and training,
- Constant integration of research, industry, and education in order to have a two-way transfer of knowledge between academia and industry,
- Environments are needed that are able to integrate education, research, and industry,
- Ensure knowledge transfer related with innovation activities of organizations.

1.6 Risk of Instability

For company leaders, the growing market and economy dynamics make it increasingly difficult to foresee future relevant developments and adjust the company accordingly. These various instabilities, such as market breaks, resource bottlenecks, terrorist attacks, difficult-to-calculate policies, embargoes, refugee crises make long-term and stable planning of global production difficult or even impossible. Consequently, factories must be designed flexibly and in a versatile manner, which cannot always be achieved in highly automated environments. The following challenges related to industry's personnel can be derived from these developments:

- Anticipation of opportunities and threats because of possible changes in business environments,
- Robust and resilient reactions to changes in the corporate environment,
- Flexibility, in order to adapt quickly to potential, foreseeable changes,
- Changeability, in order to adapt to unforeseen changes in the business environment as quickly as possible without major efforts.

1.7 Demographic Change

In industrialized countries, the population's age structure will profoundly shift to an increased proportion of older people in the coming years because of an increase in the average life expectancy combined with a reduced birth rate.[50] Often, companies are trying to cope with the aging of the workforce with the preferential recruitment of younger employees in combination with the early retirement of older employees.[51] This reduces the average age in those companies, but at the same time the experience acquired over years is lost. A more sustainable approach to this would be to keep older employees in constant working capacity throughout the period of employment and to deploy them appropriately in relation to their skills and experiences.

It is also predicted that in the near future there will not be enough skilled workers—until 2030 at least a 15% decrease in the number of potential employees is predicted, projections until 2050 show a fall in the number of available workers by over 30%.[52] So along the way employees of all ages are needed, as a result compared to the status more older employees will work in production.

A further influence on the structure of the population[53] can be found in migration movements which have grown significantly in recent years. Most people migrating to Europe these days are in the age between 20 and 50 years old, Fig. 1.10 compares the age structure of European nationals to the non-nationals coming into the countries. To enable the integration of migrants into society and to open up opportunities for industry, immigrants must be prepared for the labor markets. For this purpose, targeted training and further education formats are required, which prepare refugees and immigrants for work in local industrial environments.

[50] See Abele and Reinhart (2011), Schmid (2013).

[51] See Roth, Wegge, and Schmidt (2007).

[52] See Fuchs and Dörfler (2005), Fuchs and Kubis (2016).

[53] And the potential labor force, see Fuchs and Kubis (2016).

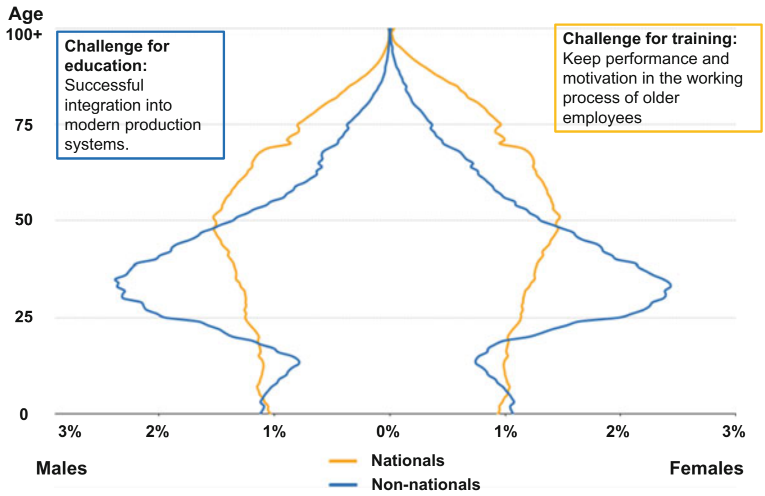

Fig. 1.10 Age structure of the national and non-national populations in EU-28, January 2016 (in %) (Eurostat, 2017)

Competency development and knowledge transfer have to adapt to these trends,[54] which implies the following:

- New forms of active learning that are based on experiences and real problem situations.
- Knowledge and competency management systems in industries need to be adapted to the new challenges.
- New methods for an efficient knowledge transfer inside and outside the work process.

1.8 Wrap-up of This Chapter

This chapter starts with the positive effects of education and training on individuals, organizations and society as a whole as a motivation. In particular, the importance of the production sector for the national economies is emphasized. Subsequently, long-term observable developments that have a decisive influence on industry and society are listed and the implications for the further development of organizations and employees at different levels of the hierarchy are presented. It is no longer enough

[54] See Abele and Reinhart (2011).

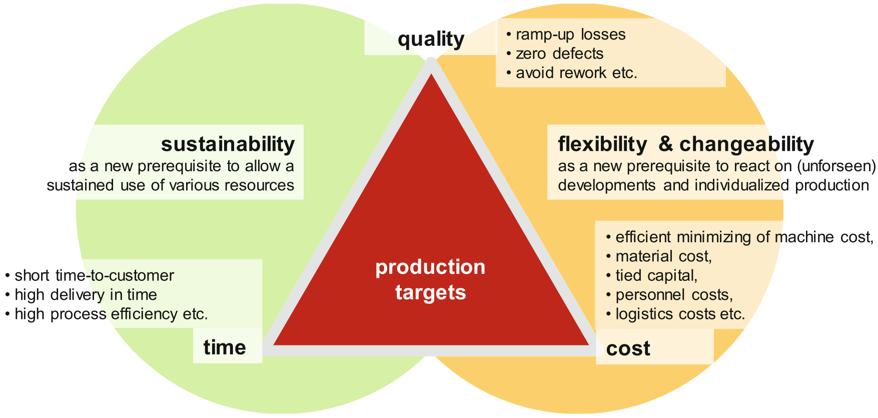

Fig. 1.11 Extended production targets

to only develop manufacturing processes, equipment, and machinery according to traditional production targets—cost, quality, and time. In light of the megatrends, industrial production targets have to be supplemented beyond the magic triangle of production by additional general conditions. Climate change, a growing scarcity of resources and demographic change mean that production targets have to be extended by the general condition of ecologic, economic, and social sustainability.[55] Furthermore, most of the presented megatrends lead to the strong need to be able to adjust quickly to changed conditions. This means that industry needs the capacity to quickly adapt to ever-changing market demands, shorter product life cycles, new technologies, the risk of instability, and the like. Consequently, the adaptability, the flexibility, and the changeability of production systems are required in respond to environmental changes as a second new general condition. Figure 1.11 visualizes the extended production targets.[56]

This chapter forms the basis and starting point for all further efforts in the field of training and further education for production with learning factories.

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[55] See Abele and Reinhart (2011).

[56] According to Abele et al. (2015) based on Gienke, Kämpf, and Aldinger (2007), Kletti and Schumacher (2011), Abele and Reinhart (2011).

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Chapter 2
Competencies for Future Production

Following from the trends shown in the previous chapter, there is a need for a great diversity of competencies, which are based on knowledge and qualifications from different fields of activity that has to be developed at all hierarchy levels and along the complete value chain; see Fig. 2.1.

Figure 2.2 shows an overview of the topics addressed in this chapter regarding the competencies for future production.

2.1 Competencies, Qualification, and Knowledge

In everyday language, knowledge, qualifications, and competences are often used almost synonymously. Knowledge in the narrower sense, skills, and qualifications are most often not the goal of (further) education, but are necessary prerequisites.[1] The ability to act in complex situations is enabled through comprehensive competency development that includes more than just transferred knowledge.[2]

Knowledge (in the narrow sense) is a foundational element of the concept of competence.[3] Additionally, competencies are based on appropriate rules, values, and norms of individual persons or entire groups. However, these rules, values, and norms influence their own actions only when they have been internalized; when they have become a part of the personality, are no longer constantly questioned, and affect the actions of the individuals. Non-internalized rules, norms, or values, on the other hand, are not action-relevant. With increasing experience, competences are consolidated.[4] Figure 2.3 depicts the relation between knowledge, skills, qualification, and competency.

[1] See Kuhlmann and Sauter (2008).

[2] See Erpenbeck and Rosenstiel (2007).

[3] According to Heyse and Erpenbeck (2009).

[4] See Heyse and Erpenbeck (2009).

E. Abele et al., *Learning Factories*, https://doi.org/10.1007/978-3-319-92261-4_2

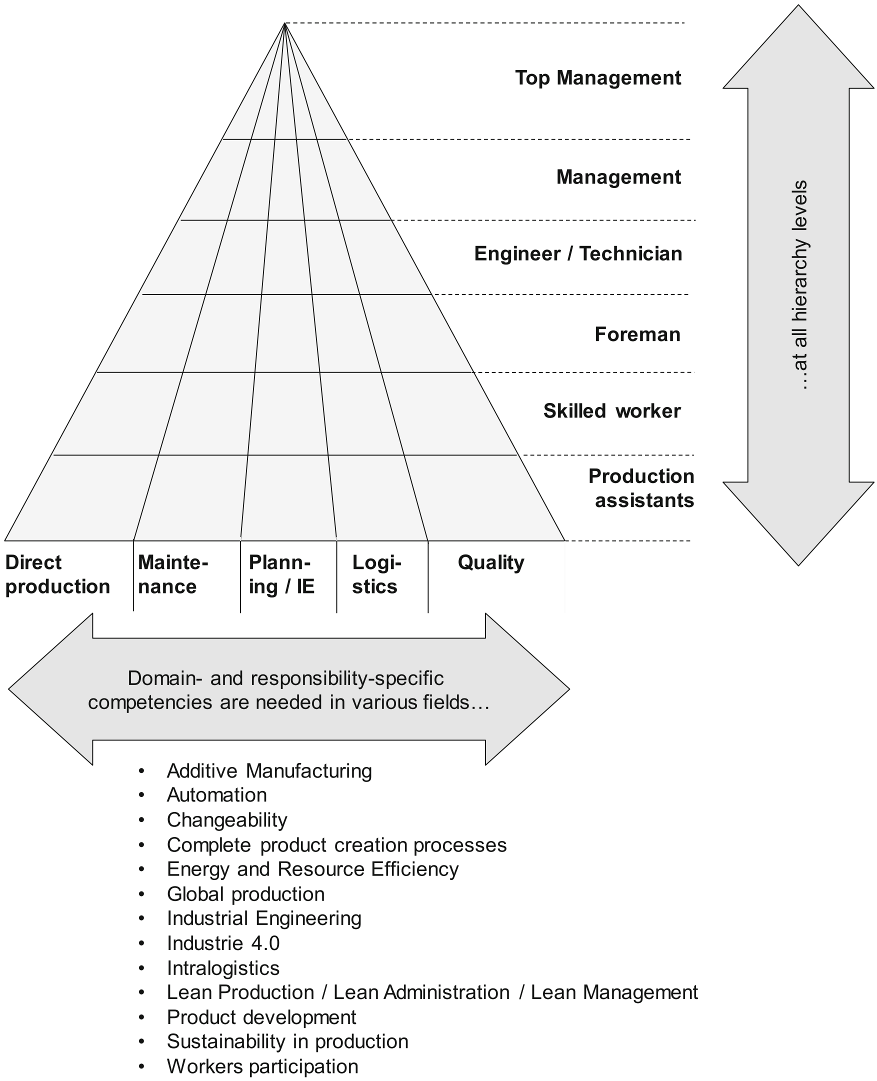

Fig. 2.1 New competencies are needed along the value chain at all hierarchy levels

2.1.1 *Knowledge*

The concept of knowledge is not clearly defined in the literature. Depending on whether business scientists, educators, politicians, philosophers, or managers define the term, given explanations are sometimes contradictory.[5] An intermixing of the

[5] Kuhlmann and Sauter (2008).

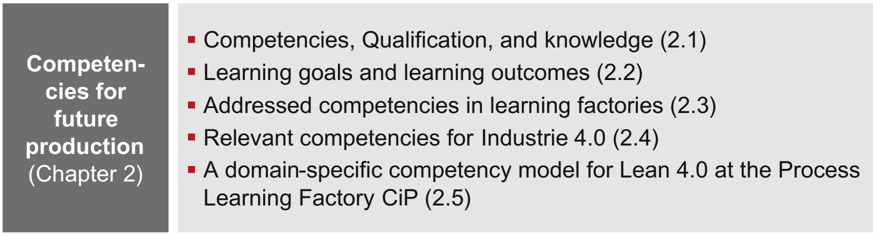

Fig. 2.2 Overview of the structure of this chapter

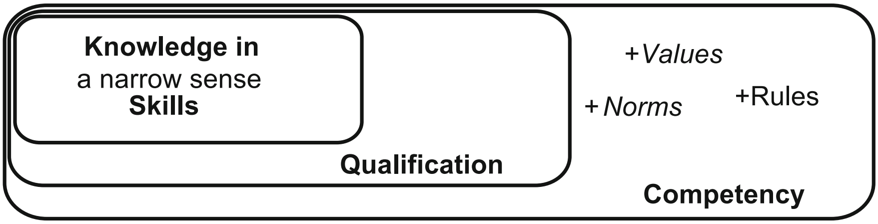

Fig. 2.3 Relation of competency, qualification, skills, and knowledge (Heyse & Erpenbeck, 2009)

different understandings in the discussion is more than a hindrance, especially for determining a training objective.[6] Knowledge arises through the networking of information. Accordingly, the European Commission describes knowledge as an "outcome of the assimilation of information through learning. Knowledge is the body of facts, principles, theories, and practices that is related to a field of work or study."[7] In the field of knowledge management, the term is defined in a similar fashion, and Fig. 2.4 exemplarily shows what is known as the "knowledge stair,"[8] which leads to the concept of knowledge using the depicted relationships of signs and data. The knowledge stair is continued up to the terms competence and competitiveness. This upper part of the knowledge stair is, however, not completely compatible with the general understanding of competence in this context.

2.1.2 Qualification

Not knowledge but adequate actions are in the center of the concept of qualification. In contrast to competencies, qualifications can be tested and verified without problem by means of a certification procedure, independently of the work process. Qualifications are an essential prerequisite for competencies.[9] In order to meet the

[6] See Heyse and Erpenbeck (2009).
[7] European Commission (2006).
[8] See North (2011).
[9] See Kuhlmann and Sauter (2008).

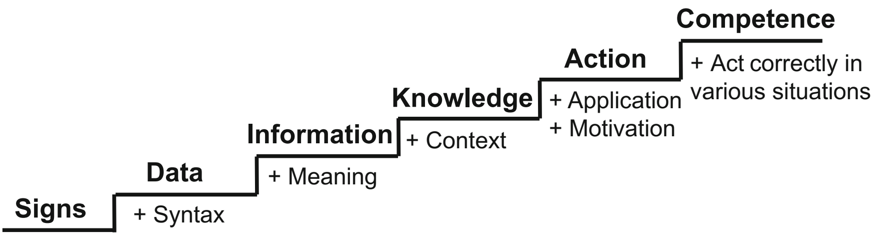

Fig. 2.4 Knowledge stair according to North (2011)

	workspace 1	workspace 2	workspace 3	workspace 4	workspace 5	workspace 6
Worker 1	4	2	2	3	3	1
Worker 2	1	1	3	3	1	2
Worker 3	3	3	3	2	4	2
Worker 4	2	4	4	4	3	3

4: Instructor
3: Can handle task and solve problems
2: Can work independently
1: Still needs training

Fig. 2.5 Exemplary qualification matrix for deployment and development of production staff

specific requirements of a job profile, personnel needs certain qualifications, which consist of knowledge in a narrow sense, abilities, and skills. Abilities are solidified systems of generalized psychophysical processes of action, which require the psychological and personal conditions.[10] Today, qualifications are often the central element for controlling deployment and development of employees in production. In most companies, for example, there are qualification matrices that describe the qualification of the individual employees for different activities and tasks, such as the operation of machines or workplaces. The qualification matrix can therefore be used for the deployment of workers and the further qualification planning inside the team. Figure 2.5 shows such a qualification matrix.

[10]See Hacker (1973).

2.1.3 Competence/Competency

The concept of competency (or also competence[11]) frequently leads to misinterpretation and confusion.[12] For clarification, three normative competence concept approaches are classified:[13]

- A behavioral, performance-oriented approach, that sees competencies as specific job-related and measurable behaviors blanking out underlying attributes,
- A generic approach, which includes underlying attributes like knowledge in the competence concept and ignores specific application contexts, and
- A holistic approach, integrating both above-mentioned approaches, i.e. competencies are conceptualized based on knowledge, attitudes, skills, performances, in explicit application contexts of professional life.

The roots of the competence concept are found in the linguistics concepts by Noam Chomsky.[14] Here, language competence is described as a person's ability to construct and understand self-organized an infinite number of unheard and unspoken sentences on the basis of finite basic elements in combination with rules for combination.[15] The close connection between competence and motivation was provided by the motivational psychologist Robert W. White. He described competences as abilities to act, formed by self-motivated interaction with the environment.[16] Accordingly, competences are seen as context-specific dispositions that built on the foundation of knowledge and skills,[17] enabling actions in open, unknown, and complex situations in a self-organized, creative manner.[18] In this context, the meaning of the similar terms "competence" and "competency" is not congruent but comparable[19]: While competence refers to a function, the term competency refers to a behavior.[20] Today, the term competency is used in an extended sense compared to its behavioral origins[21,22]; now, in addition the concept refers also to underpinning basic attributes like knowledge, skills.[23] The term "competency" is thus in the following used in the sense of the holistic approach, which regards both the underlying attributes and the

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[11]For a terminological discussion of the two notions, see Le Delamare Deist and Winterton (2005), Rowe (1995) and Teodorescu (2006) or the differentiation below.

[12]See, for example, Short (1984), McMullan et al. (2003).

[13]See Short (1984).

[14]See Chomsky (1962).

[15]Chomsky (1962).

[16]White (1959).

[17]See European Commission (2006).

[18]See Erpenbeck and Rosenstiel (2007).

[19]See also, for example, Le Delamare Deist and Winterton (2005), Rowe (1995) and Teodorescu (2006).

[20]See Le Delamare Deist and Winterton (2005).

[21]McClelland (1976).

[22]See also Le Delamare Deist and Winterton (2005).

[23]See Spencer and Spencer (1993), Le Delamare Deist and Winterton (2005).

explicit professional application context. In contrast, the term competence is used in the sense of the above-mentioned generic approach, when a specific application context is ignored.

A distinction can be made between different classes of competences. In literature, numerous classification schemes for competences can be found. Exemplarily, the following classes are distinguished[24]:

- **Socio-communicative competences** entail the ability to communicative and cooperative self-organized action.
- **Technical and methodological competences** entail the ability to mental and physical self-organized action of technical problems.
- **Personal competences** entail abilities to act reflexively self-organized.
- **Activity and action competences** entail the ability to holistic, self-organized action. This includes the use of one's own motivations, emotions, experiences, and abilities as well as all other competences for the realization of successful actions.

Specific competences can now be assigned to the four competence classes described, although the four classes are closely linked. Exemplarily, Fig. 2.6 shows an overview of the competence classes and important competences allocated to the classes in the competence atlas.[25]

2.2 Learning Goals and Learning Outcomes

Learning goals can be defined on all aggregation levels: for universities and schools, educational programs, or single educational courses. Typically learning goals and learning objectives define the intention of an educational activity.[26] Often the comprehensive intention of an educational program is defined with goals, while objectives detail those goals more specifically.[27] The term "learning goal" describes a seen target and "learning objective" a target that is aimed at.[28] Generally, in the most famous taxonomies three domains of learning goals are differentiated[29]:

- Cognitive domain, i.e. the recognition of knowledge,[30]
- Affective domain, i.e. interest or attitudes of the learner,[31]

[24] See Erpenbeck and Rosenstiel (2007).

[25] See Heyse and Erpenbeck (2009).

[26] See Allan (1996).

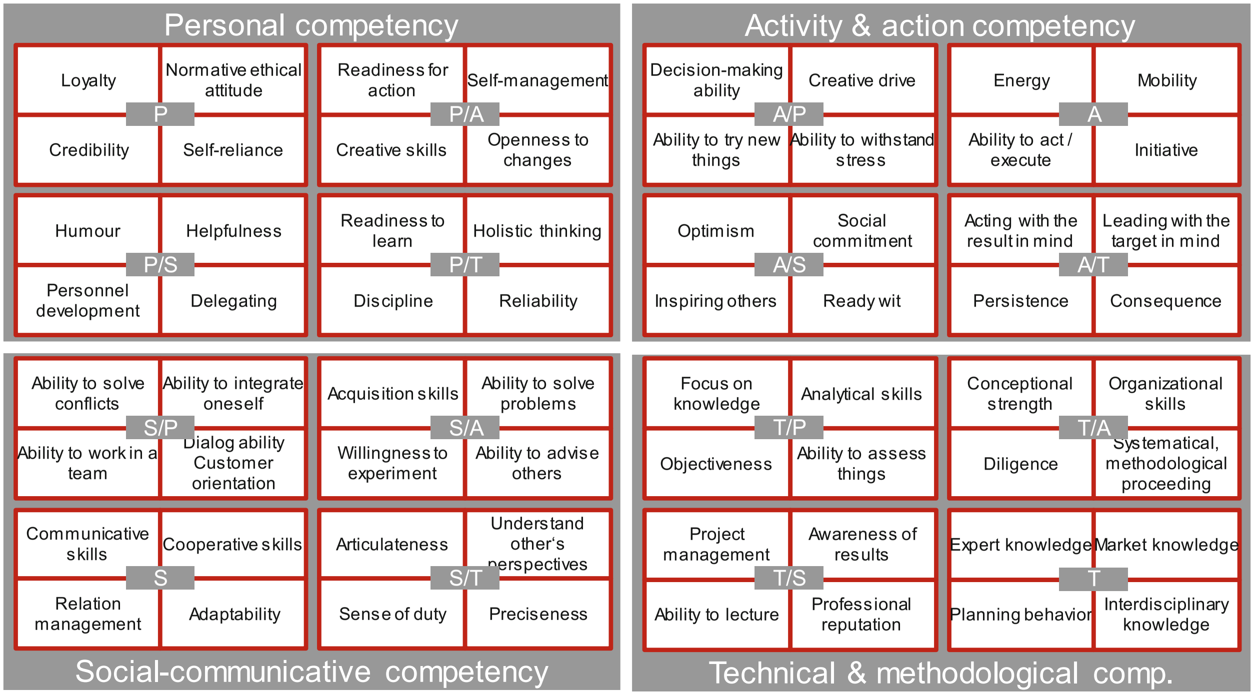
[27] See Allan (1996), Tyler (1971).

[28] See Barkley and Major (2016).

[29] See Bloom, Engelhart, Furst, Hill, and Krathwohl (1956).

[30] The most important taxonomies in this field are delivered by Bloom et al. (1956) and Anderson, Krathwohl, and Airasian (2001).

[31] The most important taxonomy in this domain is by Krathwohl, Bloom, and Masia (1964).



P: Personal competencies; P/A: Personal competencies with link to activity & action competency class; P/S: Personal competencies with link to social-communicative competency class; P/T: Personal competencies with link to technical & methodological competency class. A: Activity & action competencies; A/P: Activity & action competencies with link to personal competency class; A/S: Activity & action competencies with link to social-communicative competency class; A/T: Activity & action competencies with link to technical & methodological competency class. S: Social-communicative competencies; S/P: Social-communicative competencies with link to personal competency class; S/A: Social-communicative competencies with link to activity/ action competency class; S/T: Social-communicative competencies with link to technical & methodological competency class. T: Technical & methodological competencies; T/P: Technical & methodological competencies with link to personal competency class; T/A: Technical & methodological competencies with link to activity & action competency class; T/P: Technical & methodological competencies with link to social-communicative competency class.

Fig. 2.6 Competence atlas according to Heyse and Erpenbeck (2009)

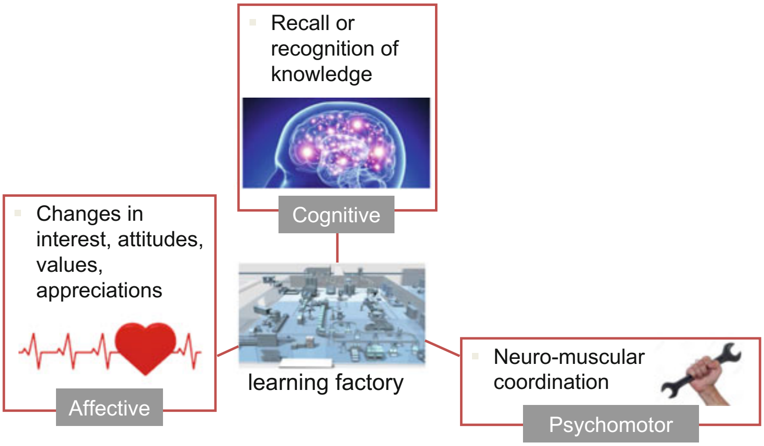


Fig. 2.7 Cognitive, affective, and psychomotor domain can be addressed in learning factories

- Psychomotor domain, i.e. task that entails neuromuscular coordination.[32]

Table 2.1 shows an overview of the most recognized learning goals taxonomies.[33]

Additionally to that, the term "learning outcome" describes the actual learning of your learners instead of the intention ("learning goal").[34] Learning outcomes that may relate to learner, subject, and teacher[35] are statements about expected effects at the end of an educational period.[36] "Defining the learning outcomes enables both the teacher and student to see what a student is expected to have achieved, and what progress he/she made with regard to his/her qualification goal".[37]

2.3 Addressed Competencies in Learning Factories

The learning factory concept offers the potential for competency development in all human performance areas (cognitive, affective, and psychomotor) and regarding all competency classes (Fig. 2.7):

[32]The most important taxonomy in this domain is provided by Dave (1970).

[33]The taxonomies are according to Bloom et al. (1956), Anderson et al. (2001), Krathwohl et al. (1964), and Dave (1970).

[34]See Barkley and Major (2016).

[35]See Eisner (1979).

[36]See Gosling and Moon (2001).

[37]Seliger, Reise, and Farland (2009).