Chapter 6

The Concept of a Digital Twin and Its Potential for Learning Organizations

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6.1 Introduction

One of the characteristics of a learning organization is the ability to self-evolve. It is, however, short-sighted to understand this self-evolving strength as a capability to only react to changing market conditions. “Anticipation,” “pro-activity,” and “being ahead of time” are buzz words that are often used to emphasize that it takes more for organizations to survive on the market. They underline that reacting alone may not be enough. Surviving may not be enough.

The major challenge nowadays is mastering the digital transformation. In the industrial sector, the digital transformation of organizations is primarily driven by the opportunity to increase productivity while simultaneously reducing costs through integration into a cyber-physical system. One way to fully tap the potential of a cyber-physical system is the concept of the digital twin and the real-time digital representation of machines and resources involved – including human resources. The vision of representing humans by digital twins primarily aims at increasing economic and technological benefits: errors are avoided, capacity is exploited more efficiently, and time to market is significantly reduced. In the case of machines, these objectives can be achieved, for example, by computing their technical specifications such as functionality, performance data, and maintenance requirements or intervals in the digital twin. In order to achieve efficient planning of human resources, similar *specifications* of humans must be used. These can be data on job, qualification, and skill profile, certainly also data related to performance, e.g., the amount of time required to perform certain activities. This justifiably raises questions of overarching monitoring and control that cannot only be addressed from a legal viewpoint. An educational perspective is needed to answer the question as to how this new and extended *transparency* of humans affects their learning. Another

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challenge is to model human skills in the digital twin, so that these data serve automation purposes. In addition to that, it should be much more interesting to consider that, in contrast to machine capacities, human skills are a dynamic factor and ideally grow over time. Humans ideally learn at work, their skills grow, the expertise deepens, humans evolve, and they learn to deal with novel challenges. Specifically when looking at informal and unintentional learning, a particular human characteristic comes into play: the human ability to deal with ambiguity, vagueness, and uncertainty. The human digital twin must therefore be designed to capture and, above all, support human learning and their further development in order to realize the organization's ability to self-evolve.

In this article, first, the characteristics of the learning organization are described in Chap. 2. The learning organization concepts considered there emphasize the importance of team learning. The third chapter provides definitions of the digital twin and the view of what objectives the digital twin should achieve and how this can be done. The fourth chapter brings together and discusses both views – that of the learning organization and that of the digital twin concept. The aim here is to clarify which educational requirements should be taken into account in the design of the digital twin in order to achieve a working environment that is conducive to learning when using the digital twin and which constellations, on the other hand, can stand in the way of it. The article closes with a discussion and an outlook on further proceedings.

6.2 Approaches to the Learning Organization

Only organizations that change will remain – a truism that may be reread in any management and leadership manual. Change is vital because the market changes constantly: new competitors appear, customer needs change, new products are launched, laws and regulations are adapted, technology advances, and complexity grows – these are just a few examples for many possible changes that organizations face. Everything else is in motion so organizations must likewise keep moving. What may sound like stating the obvious fact still remains to be a great challenge: The imperative of change is in fact an imperative of learning because learning is at the heart of change.

6.2.1 *Learning to Change, Changing to Learn*

Respectively, theories of the learning organization revolve around the organization's ability to change. Argyris and Schön (1996) coined the term organizational learning and tied their understanding of the quality of learning to the quality of change: Only far-reaching change – that lead from correcting specific errors to reassessing underlying theories and, finally, to redefining the organization's learning

system itself – enables organizations to go beyond and ensure growth and development. Change plays a main role in the concept of the learning organization by Senge (1990) as well; it is rooted in a power of creation that enables an organization to draw an impact on itself and its environment. In his concept, teams are the place where organizational learning effectively takes place. Kim et al. (2017) emphasize the importance of steadiness and consistency of change and affirm continuous learning as the main enabler for organizational learning. In the works of Garvin et al. (2008), organizational learning is regarded a strength of great importance, simply out of the fact that what needs to be learned is unpredictable and therefore most challenging.

6.2.1.1 Learning as Change from within

According to Argyris and Schön (1996), organizational learning basically occurs when a mismatch between action and outcome is resolved, but it is the depth of change that makes the difference and leads to the distinction of three types of learning:

- *Single-loop learning* occurs when individuals detect errors and correct them by taking appropriate action with direct problem-solving effect. No further action, however, is taken as to ask for the *why* of the error nor are governing procedures and policies changed. The knowledge about how to correct the specific error remains at the individual level. The organization's overall objectives and its strategy remain untouched.
- *Double-loop learning* on the other hand goes beyond: It involves modifying those same policies and procedures. Changing organizational structures and strategy is not a task that can be accomplished by the individual alone. It means to address and discuss the initial error with others, to come up with ideas for new procedures and to implement appropriate change which then will be communicated with the affected parties or throughout the whole organization. Learning, then, exceeds the individual realm and benefits the organization. Knowledge transforms from individual to organizational knowledge.
- *Deutero-learning* – the term is borrowed from Gregory Bateson's understanding of second-order learning, i.e., learning how to learn. It occurs when organizations understand how single-loop and double-loop learning works. Deutero-learning changes the learning system itself and enables organizations to create a framework that specifically promotes learning.

In this sense, organizational learning challenges the individual learner to question what they do and why they do it as an individual but also on behalf of the organization as a whole. This can only be done by confronting with one's own actions and the underlying theories as well as by seeking the confrontation with those of others. Only then, individual learning results are inscribed in the organizational learning system.

6.2.1.2 Team Learning

Senge (1990) considers learning a phenomenon that comes natural to the individual and concludes, therefore, that an organization also can learn, i.e., be a learning organization. However, the organization's ability to learn is subject to the influence of organization-specific characteristics that determine how and what is learned. In fact, only the mastery of five – as Senge calls them – disciplines enables an organization to learn; their negligence on the other hand hinders learning:

- *Systems thinking* is founded on the basic understanding that organizations are complex systems. A learning organization is characterized by its ability and its efforts to reach a deep comprehension of how actions, behaviors, and events are connected to each other and that not only visible but also non-visible processes exert their influence. The unique character of an organization's system is reflected in a symbolic, formal language, in behavioral patterns. They need to be thoroughly assessed before effective solutions of existing problems may be reached and, respectively, before effective learning may take place (Senge 1990; Senge et al. 2004; Watkins and Kim 2018).
- *Personal mastery* refers to the individual's personality development and is characterized by continuous striving for growth and by recurring reflection of one's own abilities, which in turn can have an influence on the individual's work in the organization. The individual's continuous personal development contributes to the organization's further development. To excel in this discipline, personal mastery is understood as a lifelong process and encompasses two main activities: First, a clear idea of what (goal) is important and why (for what purpose) and, second, a constant reality check, which shows the current position in relation to those goals and purposes being pursued. Central to the idea of achieving personal mastery is the free will; one cannot be forced to it (Senge 1990; Senge et al. 2004).
- *Mental models* enable to critically reflect on unconscious, unquestioned, and often tacit presuppositions. Mental models control individual actions. Essential for learning is the understanding of one's own mental models and the realization that they are not an accurate representation of reality. For a learning organization, it is crucial to recognize the unsystematic yet influential nature of mental models and to understand that they differ from person to person. Efforts to raise awareness of one's own mental models and reaching an understanding with others despite their different perspectives foster learning (Senge 1990; Senge et al. 2004).
- *Shared vision* promotes creativity, eagerness to experiment, and courage. It opens up new ways of thinking and acting by bringing together and sharing different viewpoints. It closely corresponds with the discipline of personal mastery by opening up for the individual goals and purposes. A learning organization offers opportunities to clarify individual visions, goals, and purposes, to negotiate them and finally to co-create a shared vision (Senge 1990; Senge et al. 2004).

- *Team learning* values dialogue and discussion in balance. Dialogue pursues the goal to enrich the common understanding and to give the individual the opportunity to overcome their own limits of understanding. At this point, agreement is not the issue but discovering new aspects. Discussion serves the goal to find alignment and reach a decision. Both forms of discourse – dialogue and discussion – are characterized by respect, honesty, and openness. Teams may shift from one form to the other back and forth as seems appropriate and at the team's pace. Teams should be aware of group dynamics that undermine learning such as superficial consent or oppressed thoughts. They are therefore free to define their own rules and take appropriate action if those rules are not adhered to. A learning organization considers teams as the “place” where organizational learning eventually and effectively takes place (Senge 1990; Senge et al. 2004; Watkins and Kim 2018).

A learning organization is a complex system consisting of individuals who are no less complex in themselves and whose actions are an equally complex process. In this view, learning must be seen as subject to the influence of various interdependent factors. These factors sometimes reinforce each other or are in conflict with each other. Therefore, individual learning beneficial to organizational learning cannot be taken for granted. It can only be cultivated in the encounter of individuals collaborating effectively in teams where individuals express explicit and tacit influence factors and collaboratively work on common solutions.

6.2.1.3 Continuous Learning and Change

A learning organization according to Watkins and Marsick (1993) is characterized by processes, structures, and practices that are at all levels directed toward learning: individual, team, organization, and society. Training is an important factor in a learning organization, but its importance is surpassed by informal learning, that kind of learning that takes place when carrying out work-related activities. When learning and working are intertwined, learning occurs on a continuous basis and creates likewise continuous change with an impact not only on the individual and on teams but on the organization and eventually on society as well. Learning individuals change their view of the organization and give a new meaning to their work. This in turn demands the work and the organization including its perception by society to change. A learning organization is built on the following imperatives:

- *Create continuous learning opportunities* by designing work in such a way that learning may be accomplished while working and by offering ongoing education.
- *Promote inquiry and dialogue* in order to give the individuals the opportunity to express their perspectives while at the same time listening to those of others. This includes asking questions, giving feedback, and experimenting, all of which are explicitly supported and valued.

- *Encourage collaboration and team learning* by empowering groups to access different modes of thinking so that working and learning go hand in hand.
- *Empower people toward a collective vision* by enabling them to jointly engage in vision creating, i.e., setting objectives, owning, and implementing them. Responsibility is allocated where decisions are made so that individuals are able to take responsibility for their actions.
- *Connect the organization to its environment* so that the interdependency between the organization and its environment becomes clear which enables the individual to understand the impact of their actions on society and the impact of society on their actions.
- *Establish systems to capture and share learning* by explicitly defining learning as an organization's objective assisted by appropriate technological systems. They are used to create learning opportunities and to disseminate learning content.
- *Provide strategic leadership for learning* by nurturing a leadership culture that views learning as a strategic asset and uses it. Leaders are keen to model, advocate, and support learning (Kim et al. 2017; Marsick 2013; Marsick and Watkins 2003; Watkins 2000; Watkins and Kim 2018; Watkins and Marsick 1993; Yang et al. 2004).

Organizational learning is a continuous learning, rather a steady process than a one-time event, e.g., due to a specific need for change. What is special about this view is that it emphasizes the exploration of the unknown as a primary characteristic of learning.

6.2.1.4 Specific Activities Fostering Individual Change and Learning

Learning is a phenomenon that, like change, is continuous. In this sense, one may state that organizations are learning organizations by nature. Two aspects, however, get in the way of this first conclusion: *On the one hand*, learning at the individual level is limited to its effects to the individual level, if learning results do not lead to a change of individual behavior. Furthermore, the organization benefits from individual learning results only when shared, discussed, and jointly exerted. *On the other hand*, the *what* of learning is an important aspect, too. Learning in a constructivist sense is subject to many different influence factors and is therefore also to be regarded as subjective experience with an open outcome. For example, learning to speak openly about one's own mistakes and, thus, enable others to learn from them as advocacy mistakes (Oser et al. 2009) requires a supportive organizational environment. Otherwise, individuals tend to hide mistakes in order to avoid sanctions, and a repetition of the same mistake becomes probable (Harteis et al. 2008).

Individuals' informal learning at work is a matter of fact that cannot be avoided at all. However, for an organization, it is crucial that individual learning leads to change of behavior, practices, and thinking. The 3-P model of workplace learning by Tynjälä (2013) provides a comprehensive overview of the complex interrelation

between individual learning and its influence factors determining whether behavior is maintained or changed. In this model, the specific *activities* at the individual level are the result of a negotiation between *learner factors* such as prior knowledge and *learning context* such as organizational structure. But before any action is taken, the individual's *interpretation* determines if and how the individual engages in activities beneficial to learning. These activities create *learning outcomes* at an individual and organizational level and in turn – closing the cycle – shape the input factors: learner factors, learning context, and interpretations. This cycle is overall governed by the surrounding *sociocultural environment* including values, policies, and customs in a society with an effect on the organization.

6.2.2 Conclusion

The learning organization cultivates learning. It seeks to understand what needs to be learned and how it is accomplished. It values and realizes change as a result of learning at both the individual and the organizational levels. Errors are an opportunity to rethink current practices and the structures behind them in order to adapt and change them. Being aware of its own complexity, the learning organization strives for a deep understanding of existing interrelations and seeks for a reflection in an overall context. Individual perspectives, interpretations, and experiences – from in- and outside the organization – have a significant influence on learning. Efforts are made to reach an awareness and understanding of these influence factors and their effect on action. The learning organization provides sufficient space for exchange and various forms of collaboration and interaction – such as networks, think tanks, and teams – that may exceed organizational and disciplinary boundaries. Teams are considered as *power plants* that are able to transform individual learning into organizational learning, provided that they are granted extensive autonomy. Teams are enabled to share individual thoughts and ideas, on the basis of which they freely co-create visions, objectives, and purposes for the organization. Work itself is regarded as a place of learning and therefore encompasses activities that promote learning. In addition, this includes reflection and evaluation of one's own actions compared to the objectives to be achieved.

6.3 The Digital Twin

In the production system, digital technologies allow the integration and interconnection of the involved resources and processes by connecting them with each other via the Internet using sensors and actuators. This enables sensing, monitoring, and controlling remotely and in real time (Kritzinger et al. 2018). As the virtual equivalent of the physical system, a digital twin “can be used to simulate it for various purposes, exploiting a real time synchronization of the sensed data originating from

the field-level and is able to decide between a set of actions with the focus to orchestrate and execute the whole production system in an optimal way” (Kritzinger et al. 2018, p. 1016). Josifovska et al. (2019) consider the digital twin “as one of the main enablers for digital transformation” (p. 403).

6.3.1 *Approaches to a Definition of the Digital Twin*

The concept of the digital twin is still in its infancy. The understanding of what the digital twin is and what it is supposed to do varies depending on the perspective of the regarded research. With a focus on the industrial sector and therein on manufacturing, a digital twin combines information of a machine, for example, in such a way that its properties and functions are digitally represented in the virtual world as they appear in the real world. “Mirroring” (Grieves and Vickers 2017, p. 93) was the term to which the attempt of virtually representing physical objects initially referred; moving on to the use of the term digital twin is due to the fact that today’s advanced technologies allow a more integrative and reciprocal link between the virtual and real world. Characteristic and distinct feature of the digital twin is the automatic exchange of data in both directions via this link: from the digital twin to the real object and from the real object to the digital twin (Grieves and Vickers 2017), this feature distinguishes the digital twin from the digital model (only manual data exchange in both directions) and from the digital shadow (automated data flow from the real object to the digital shadow but only manual data flow back) (Kritzinger et al. 2018). The digital twin “emphasises interaction, communication and collaboration between physical space and cyber space” by creating meaning out of the exchanging data (Tao et al. 2019).

However, regarding the question of with what kind and with what amount of data the digital twin should work, the current ideas differ. Grieves and Vickers (2017), for example, understand the digital twin as “a set of virtual information ... that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level” (p. 94) and that ideally any information is obtained. Glaessgen and Stargel (2012) develop a definition derived from their work in the aviation sector, which nevertheless illustrates the great potential of the digital twin also in general: “A Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin” (p. 7). In terms of data quality and quantity, they argue to take into account all possible cause-effect interrelations including adjacent processes such as “on-board integrated vehicle health management (IVHM) system, maintenance history and all available historical and fleet data obtained using data mining and text mining” (p. 7). “The digital twin is not a data monster, which includes everything from all lifecycle phases,” however, is the position of Boschert and Rosen (2016), who tie the criterion of comprehensiveness of the digital twin to the criterion of usefulness; they state that the “general vision of the digital twin refers to a compre-

hensive physical and functional description of a component, product or system, which includes more or less all information, which could be useful in later lifecycle phases” (p. 66).

In summary, the digital twin can be understood as a means to virtually mirror the automated production system and to work with the extensive data generated and processed there in. These data contain useful information to be exploited for further automation and for increasing productivity but also for realizing quality objectives. They are put into context by the digital twin and are thus operable for the achievement of the abovementioned goals. Opinions differ as to how much data is needed: The extensive understanding of the digital twin demands all available data, the lean approach, however, operates with useful data only.

6.3.2 Purpose of the Digital Twin

6.3.2.1 Technological Purpose

From a technological point of view, the main advantage is that with today’s means large volumes of data can be processed in rich variety in real time. Different types of data from different sources are brought into consistency. This data is used to improve production by accurately planning and executing all production steps including upstream and downstream processes such as supply as well as maintenance. Deviations and anomalies at any level can be managed quickly and thoroughly. Processing the data for the purpose of simulating different scenarios opens up new possibilities for improving production. Working with probabilistic data allows to predict possible failures and helps to be prepared for unexpected events. By taking a holistic view of the entire value chain, experiences from all phases can be used in all phases: For example, efforts in service and feedback from customers can be taken into account in product development without much delay. Improvements can thus be implemented quickly and in a customer-oriented manner (Boschert and Rosen 2016; Glaessgen and Stargel 2012; Kritzinger et al. 2018; Tao et al. 2019). Promising potential is seen in to better understand, monitor, control, maintain, and overall improve the production process. The digital twin is also intended to support humans in making their work more creative by adding structure and meaning to the large data volume and by combining a variety of data in experimental scenarios (Boschert and Rosen 2016; Tao et al. 2019).

6.3.2.2 Economic Purpose

An undisturbed data flow and the targeted use of data make a decisive contribution to productivity, a significantly reduced time to market, and an optimized product design. The digital twin works with data from different systems and makes it available to the specific phases of the product life cycle. In this way, simulations can

be run in all phases to achieve the optimum process. It is modular and provides standardized interfaces, analyzes historical and real-time data with the help of algorithms, and has a well-defined structure that allows later upgrades and a constant evolution along the value chain. Data from early phases are used to optimize downstream phases; data from downstream phases are in turn used to optimize the upstream phases. They then serve for a faster design and launch of adapted or new products and procedures. By realizing not only cost but also competition and market advantages, the digital twin generates added value along the whole value chain. Of the extensive data, only those that can be considered essential are condensed into relevant information within the digital twin. Properties, activities, and events that are not used for streamlining the production system will not be taken into consideration. Thus, the digital twin can be described as a lean model and can be regarded as a means to increase overall efficiency (Boschert and Rosen 2016; Kritzinger et al. 2018).

6.3.3 *The Digital Twin for and of Humans*

In order to explore the potential of the digital twin, a consideration from a human perspective is important in two ways.

One perspective sheds light into the situation where humans work with digital twins to control and manage a cyber-physical system. Here it is to be considered that the increasingly digitally integrated production process confronts humans with a significantly changed work situation. The changes are different depending on the area of work. The area of product development, for example, benefits from the possibility of simulating the properties of planned products instead of testing them in a time-consuming and costly manner. The end user's experience with an already existing product provides an enriched view on how the product can be further developed. The integration of information from adjacent work areas such as purchasing, controlling, etc. can also ensure that changes to the product are simulated in multiple perspectives and thus checked for their usefulness at an early stage. Seen in this way, the digital twin contributes to an enrichment of the work located there. Furthermore, by bringing together information from different areas of work, an effective communication is especially required. A common understanding that transcends disciplinary boundaries will become increasingly important if effective cooperation is to succeed (Gräßler and Pöhler 2017; Tao et al. 2019).

The work situation in production itself, however, faces changes of a different quality. The digital twin contributes to an increasingly automated production process, rendering certain human activities obsolete. Not only dangerous and monotonous work is subject to substitution but also planning and evaluative activities. Also, decisions on the allocation of tasks, for example, are more and more being made by computer systems. This will lead to a shift of human work from performing to

monitoring. In addition, the use of sensors and assistance systems to check the correct execution of work steps can easily be used for surveillance purposes (Gräßler and Pöhler 2017). In the case of inaccurate and erroneous data resulting in erroneous decisions, it will become necessary for humans to recognize these errors and be able to correct them and overrule the computer system. This requires new skills (Nokelainen et al. 2018; Tao et al. 2019).

Another perspective to be considered is the human digital twin, i.e., the representation of humans in the virtual world. Following the basic functionality of the digital twin in a technical context and applying it to humans, then such information is required which reflects the human's role embedded in the production system. The objectives pursued there – increasing overall quality, avoiding errors, and reducing time to market – apply here as well. This means that the human digital twin contains the human's specific tasks, their abilities, and probably such information that allows to tailor assistance systems to humans for a better job execution (Gräßler and Pöhler 2017). To capture real-time information, work activities performed by humans have to be recorded; to compare real-time data with historical data, these activities have to be stored. Information that describe human characteristics, abilities, and activities have to be put into a form that the digital twin can work with. Ideas are therefore needed here as to how this can be achieved. As mentioned above, human abilities undergo significant change over time; ideally, they grow. Here too, a way must be found to take account of this growth in skills, the deepening of expertise, and human creativity in the digital twin, so that the virtual human grows along with its real counterpart. Therefore, learning activities are to be planned with the help of the human digital twin. Here, the digital twin serves to help compensate for lacking skills or for qualifying purposes in order to prepare for new planned tasks for which humans do not yet possess the knowledge, skills, and expertise. Another way of enabling humans to effectively take part in the virtual world – considering “their current schedule, preferences, skills and experience” (Graessler and Poehler 2017, p. 293) – is an interactive design of the digital twin, e.g., not all decisions by the human digital twin are made autonomously, and some decisions are to be approved or even corrected by the physical human. The human digital twin is supposed to learn from this interaction and find a pattern in the human's behavior in order to emulate it and ultimately take over with autonomous decisions. The integration of humans via their digital twin is rooted in the effort to enhance the production system by leveraging valued human skills (Graessler and Poehler 2017). Which valued human skills these are is not described in detail. But if the digital twin is to emulate humans, this creates demands on the digital twin to deal with ambiguous human behavior as well. From an educational perspective, ambiguity tolerance is a central human characteristic enabling them to successfully work even with conflicting, vague, and incomplete information. As of designing a suitable digital twin in this respect, the binary logic does not suffice; algorithms are necessary that allow an ambiguous attribution of computational elements (Ansari et al. 2018).

6.3.4 Conclusion

The digital twin is a key technology for the further development of cyber-physical systems by aggregating the data into consistent relevant information and making it usable to control, manage, and advance the cyber-physical system. To unfold its full potential, the design of the digital twin takes the complex interrelations within the cyber-physical system into account. The specification of clear objectives and purposes is furthermore necessary in order to decide which data have to be processed for which purposes and in what manner. Thus, it has the potential to make the system as a whole more flexible and better manageable. The question as to how the digital twin may support human learning – whether as *operators* of machines controlled by digital twins and whether as *controllers* of their own digital twin or *controlees* by their digital *self* – will be discussed below.

6.4 Learning with the Digital Twin

Organizational learning depends on human learning. Humans learn continuously, not only in purposeful structured learning situations but also all the time. They are constantly engaged in perceiving their environment as well as their own internal processes and relating both of them to each other. In this way, they make sense of the environment and of themselves being part of it and to seek to exert influence on both. A learning organization supports individual learning and encourages team learning. It creates the necessary freedom for change as a result of individual and team learning and allows this change to affect the organization itself, its structures, processes, and self-conception. The digital twin is expected to significantly advance cyber-physical systems, but will it bring the learning organization to the next level as well? Tynjälä's (2013) 3-P model of learning at the workplace (see Fig. 6.1) takes into account the above-elaborated characteristics of a learning organization; specifies preconditions (presage), activities (process), and results (product); and considers surroundings (sociocultural environment) influential to learning. It is therefore an appropriate foundation for the discussion whether and how the digital twin influences human learning.

Following the idea that learning and working ideally should be intertwined, we will first look at the *activities* assigned to the *process* phase, namely, *doing the job itself*:

The idea of how the digital twin may support informal learning while working is pursued, for example, when its potential for meaningfully structuring an otherwise unmanageable and overwhelming data volume is discussed, even if this feature is not explicitly described as beneficial to learning (Tao et al. 2019). Reducing external or inefficient cognitive load (which occurs when dealing with irrelevant tasks) in favor of relevant or effective cognitive load – which activates cognitive resources, helps retrieve knowledge from the long-term memory, and enables to recognize

Fig. 6.1 The 3-P model of workplace learning from Tynjälä (Tynjälä 2013) Reprinted by permission from Springer Nature: Toward a 3-P Model of Workplace Learning: a Literature Review by P. Tynjälä, 2013, *Vocations and Learning*, 6(1), p. 14. Copyright 2013 by Springer.

patterns and build routines – fosters learning and expertise development (Paas et al. 2003a, b). The core question here is whether the logic of aggregating and structuring the data by the digital twin corresponds to the human mental model or deviates from it and how the one or the other is to be viewed. Also of interest is the extent to which the digital twin is able to respond to the varying human capability to cope with cognitive load depending on various influence factors: Attention, emotions, and environmental stimuli can exert a positive or a negative effect (Pekrun 2018; Schwarz 2019).

For developers of the concept or a framework of the digital twin in the fields of mechanical engineering, systems engineering, or computer science, it can be assumed that working on the digital twin enables learning. For the following reasons, defining the appropriate mathematical models and algorithms for the digital twin to combine the huge amount of data into meaningful, sufficient, and relevant conclusions is a task that requires both deep expertise and creativity on the designer's part. The digital twin offers a task rich of learning. Once the architecture has been defined, the question arises as to how much freedom the digital twin offers to its user.

Reflecting and evaluating one's own work experience: The digital twin is supposed to enable humans to participate in the cyber-physical system, to control, and

to manipulate it in order to ensure high data quality, to give one example (Graessler and Poehler 2017). Regarded as an integral part of the cyber-physical system, humans should be given the opportunity to manipulate their own digital twin and to work with their own performance data in order to reflect on it and to evaluate it. This would extend the notion of the human's role by providing them extensive control over their own learning and by actively working with their digital counterpart. Such a feedback feature, in fact, collides with the definition of the digital twin where data is exchanged automatically in both directions. In addition, reflecting on one's own learning on the basis of objective data only – e.g., task performance, results, and comparative data – does not consider the whole picture if emotional states and reactions – such as (dis)satisfaction, relief/stress, joy/nuisance, etc. – are left out. If and to what extent it is possible to accurately express human feelings in computable data is one question; if and to what extent expressions on feelings can be computed is the other question. Developing and working with fuzzy sets in algorithms or finding ways to combine machine and human learning are research directions that may find adequate solutions here (Ansari et al. 2018; Wang et al. 1999).

Learning also happens when errors are made. Reflecting upon errors paves the way for learning. Learning from errors enables – provided it is valued as a chance for correcting unsuitable practices and structures – the construction of negative knowledge that provides information about what does not lead to the intended outcome. Negative knowledge has the important function of protecting positive knowledge (Oser et al. 1999). However, it is a challenge to represent negative knowledge in its epistemological function for human's competencies in the digital twin.

Tackling new challenges and tasks: The possibility to run simulations with the digital twin may also be considered as a learning facilitator, as it creates room for experimenting. Thereby, space is given for choosing new challenges, finding creative solutions, and making own experiences on the way. However, the objectives of reducing the volume of data on the one hand and enabling simulations on the other hand are in conflict. A too restrictive provision of data in the sense of a lean model of the digital twin can limit potential simulations. The ability to create something new, to experiment, and to rethink old practices, however, is a central characteristic of the learning organization, of learning per se. Tackling new challenges, advancing personal mastery, creating, and innovating create competitive advantages and improve the market position (Garvin et al. 2008; Senge 1990; Tynjälä 2013).

Collaborating and interacting with other people, participating in networks, and participating in formal training: The use of the digital twin for formal training purposes is conceptualized for learning factories where the digital twin's potential to support human learning, interaction, and collaboration is researched (Brenner and Hummel 2017; David et al. 2018; Uhlemann et al. 2017).

Product phase, decision-making and problem-solving/understanding/identity: In the case of computer-generated decisions, humans face two challenges. First, the task of monitoring, correcting, or overriding decisions made by the computer system demands that humans understand on what the decision is based, what triggered it, and to what consequences it leads. They must understand the processes of the otherwise autonomously running operation and be able to classify deviations from

normal operation in order to take appropriate action; in short, they must know and understand the context. There is a danger that the complexity due to an increasing degree of automation becomes overwhelming (Ahrens and Gessler 2018). Second, if humans are entrusted with the task of controlling their own digital twin, for example, to set their own preferences, to assess their own learning progress, to recognize learning potential, this presupposes that humans are aware of their own learning. However, learning is not always conscious to the learner: Implicit mental models influence learning, as well as established routines may be applied without having to think about it deliberately (Harteis and Billett 2013; Senge 1990). Learning also encompasses the unplanned, unintended, and unforeseen, which is of particular importance for the development of procedural knowledge. How a digital twin can support here is to indicate possible learning goals – presupposing that the digital twin appropriately represents the individual's stock of knowledge.

Team work: With the objective of operating along the entire value chain, the digital twin covers a wide scope and acquaints the humans involved in the production process with corresponding far-reaching teamwork. However, how team learning is fostered – be it by handling the digital twin of machines or be it within the human digital twin – is widely neglected in current research. With Senge's sense of team learning in mind, where there is no organizational learning without team learning, this is an aspect that needs to be addressed. Successful teamwork is essential for overcoming limitations in thinking and is a source of creativity, innovation, and change that should not be underestimated. Teams are empowered to make decisions. Joint decisions create a higher level of commitment and a shared understanding of what needs to be achieved. A shared vision is co-created (Senge 1990; Watkins and Marsick 1993). To comprehend and to virtually model the digital twin of machines is one thing. It is challenging to find approaches how to model humans within cyber-physical systems, however, particularly if these models comprise data on learning. It is necessary to distinguish the challenge of modeling individual learning within a digital twin and the challenge of utilizing the digital twin for the support of individual learning within a learning organization. From today's perspective, it seems particularly challenging to include team learning with its characteristics and possibilities in the concept of the digital twin. Finally, inherent in the concept of the digital twin is the idea of enabling human creativity, a quality of which computer systems, at least at present, are not capable.

Sociocultural environment: The problem of a lack of context also arises when collaboration transcends corporate, national, and legal boundaries. Different learning cultures come together, which is not a new phenomenon. It has been the case for some time that global teams work together. However, if the digital twin is also supposed to support learning, the question arises as to which policies with regard to learning and which learning culture should be built in its logic. This includes different aspects that foster learning, e.g., providing feedback, error tolerance, the freedom to set individual preferences, critical thinking, etc. The underlying learning culture also determines whether these features are accepted or not and whether their specification is perceived as restrictive or lack of guidance. The learning organization is characterized by systems thinking and an awareness of its own complexity,

as mentioned above; this complexity increases when different learning cultures need to be re-negotiated. To address this problem, the digital twin may provide different features depending on the specific learning culture. Whether such an approach is technically feasible, cannot be fully discussed at this point.

Presage phase: The greatest challenge, however, for designing a digital twin beneficial to learning pose the pre-conditions of learning, especially the *learner factors* and the *interpretations* and the *learning context* to a certain extent as well. Data handling within a digital twin poses a particular challenge. What data are to be considered relevant with regard to the digital twin of a machine as opposed to that of a human? Data on the geographical position, the exact performance, the physical features of a machine, or a product are certainly to be considered useful in order to avoid idle times, to perform maintenance work, etc. They are easily obtained – compared to data on humans. Data of comparable quality on humans may be in violation of privacy which should not only be considered from a legal point of view. It also raises questions relating to learning, namely, regarding the freedom of choice, psychological safety, and dealing with errors (Garvin et al. 2008; Senge 1990; Watkins and Marsick 1993). Automatic data collection with the help of sensors may be perceived as monitoring and are easily to be misused and exploited; in certain work environments with dangerous or intense work activities, this monitoring may be considered helpful and therefore be accepted. In all cases, however, serving a reasonable purpose or not, data on employees needs to be protected.

The digital twin serves the idea of increased productivity by optimizing the whole production process and reducing time to market. This requires a certain degree of standardization. The need for determination and standardization within cyber-physical systems on the one hand and the challenge of appropriately representing individual knowledge and development within a digital twin on the other hand represent another conflict of objectives. From a technical point of view, it is possible to define functions and variables of a digital twin that determine an individual's role within a cyber-physical system. However, from an educational point of view, it is impossible to determine it in the real world – except by exerting compulsion and reducing human learning and growth to behavioristic aspects. Hence, the implementation of a human digital twin within the virtual model of an organization opens up opportunities to solve a problem within the virtual model that cannot be solved in reality. In this respect, the characteristic of the digital twin of realistically representing its real counterpart – the mirroring aspect – is not given.

6.5 Discussion and Outlook

Whether and how the digital twin can support human learning is a question that is challenging to answer. Learning depends on so many factors that cannot be easily mapped in the digital twin. Of course, measurable and observable information may be taken as indicators for learning. For example, the quality of results and the time needed to complete a task may be able to indicate a learning level. An analysis of work results over time will allow to state a progress or a decline in learning.

However, the digital twin should not only measure learning but also support it. With this objective in mind, the digital twin will have to be able to work with *invisible* but relevant learning factors such as autonomy, beliefs, cognitive processes, and emotions. Challenges can also be identified in terms of team learning. How may learning in general and learning with others be translated into computable data? Further research is needed to deepen the understanding of the interrelations of cognitive processes, emotions, social interaction, and learning.

In terms of technological complexity, the digital twin seems to be just the adequate technology. It serves to bring order into a great amount of diverse data and opens up new ways of designing the production process by combing these data in multi-variable simulations. In terms of the complexity of the learning organization, the main concern here is that the digital twin shall not violate it. The following applies to the digital twin of machines and technical systems: The more data of the physical object is available, the more accurate is its virtual counterpart, the better the mirroring. The only question here is how much effort it takes to collect the amount of data, to decide upon their relevance, and to bring into consistency. The opposite applies to humans: A most accurate and thorough representation of humans in the virtual world can show a counter-effect, since humans may perceive working conditions where extensive data on their actions and behavior are collected and stored as restrictive and controlling. Ironically, there is a risk that an excessive collection of learning-relevant data may not lead to a more accurate picture of human learning but to the *disappearance* of it. Humans may withdraw and disengage. In this regard, further investigations of what might be the right balance between human-made and computer-based decisions seem to help find promising answers.

With the potential of computer systems in general – and with the digital twin in specific – of taking over tasks formerly executed by humans, a thorough assessment is due as to what human skills are confidently replaceable. Humans are more and more expected to monitor an automated operation, not execute it themselves. The skills that they needed for operation and that they have refined over time are no longer used, but are they in fact dispensable? This is especially true in the event of a malfunction. These thoughts refer to an effect that is widely discussed as *Ironies of Automation* where skills are disused because tasks are operated by machines but then still needed for monitoring the machine-run operation, for stepping in in the event of failure and over-ruling the computer system.

In general, interdisciplinary approaches are due to find adequate solutions to the compelling questions that arise with the concept of the digital twin.

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