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CONCEPTUAL ANALYSIS
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Conceptual Change in the Face of Digitalization: Challenges for Workplaces and Workplace Learning

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The article discusses the explanatory power of conceptual change for research on workplace learning in digitalized workplaces. Interestingly, research on conceptual change is well-established within the area of science education but widely neglected within the broad area of workplace learning research. Digitalization of work establishes new quality of tasks and tools by integrating workers and machines into digital networks. Hence, conceptual change can be considered a core concept for identifying workers' successful adaption to digital transformation. Therefore, conceptual change research in the area of workplace learning in digitalized workplaces is highly relevant. The article reflects upon reasons, explores the potential of conceptual change for understanding workplace learning in digitalized workplaces, and illustrates the argumentation by exemplarily referring to digitalized farming. Finally, the article provides suggestions for future research.

Keywords: conceptual change, digitalization, workplace learning, professional development, agriculture

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INTRODUCTION

The first educational researchers who were interested in adults' learning outside school settings aimed at understanding learning in the circumstances of practice in order to improve learning within formal educational settings (i.e., classrooms). It was the seminal paper of Resnick (1987) AERA presidential address that gave the impetus that educational research also started to address issues of workplace and adult learning outside schools. Whereas, research on workplace learning meanwhile established an independent field within educational research that applies regular theoretical approaches of learning and instruction, there is still little exchange between research on workplace learning and research on school learning (Gruber and Harteis, 2011). This is the case even though several researchers analyze the interrelation between school experiences and learning through work activities (e.g., Billett, 2002; Boud and Middleton, 2003; Boud, 2006; Malcolm and Zukas, 2006).

However, it may happen that current research neglects relevant approaches of learning and instruction, particularly if focusing on individual (and particular cognitive) influences on workplace learning. Research on workplace learning investigates how individuals develop professional expertise, skills, and capacities but also professional identity and agency that allows them to tackle tasks and challenges of their work (Evans et al., 2004; Fuller et al., 2005; Malloch et al., 2011). These learning outcomes comprise the full range of understanding how a particular domain is structured and how to successfully manipulate a work environment and its tools—that is, acting responsibly and competently at work. Apart from their initial training, learning in the context of working life is considered to be of particular relevance for workers' development of required skills

and competences. This can be explained due to permanent change that processes and structures at work underlie (e.g., Hetzner et al., 2015; Illeris, 2018). Such change may result from technological development, modified customers' expectations, adaption to market requirements, etc. Workers, therefore, permanently experience novel situations that challenge their current mental models of the workplace, including strategies to solve work-related tasks and challenges. Hence, *conceptual change* at work seems to be a relevant theoretical approach to investigate such learning processes. However, almost no research exists utilizing ideas connected to conceptual change in the field of workplace learning. This discrepancy deserves a closer observation.

Currently, digitalization of work is an intensely discussed topic that outlines effects on working life as well as society and economy in general (Harteis, 2018). Within this discourse, it is widely agreed that digitalization is accompanied by wide-ranging and rapid changes for workers in production as well as in service industries. Although changing requirements have always been present in the context of work, the changes connected to current digitalization tendencies are discussed to go far beyond experiences from automation and rationalization present in the last decades (McAfee and Brynjolfsson, 2017). Hence, the digitalization of work seems to be an appropriate exemplary arena for reflecting upon the explanatory power of conceptual change without denying that ideas of conceptual change are similarly relevant in other workplace learning contexts.

This contribution briefly sketches research on conceptual change and the discussion on digitalization of work in order to reveal the relevance of conceptual change for understanding workplace learning in times of digitalization. It searches for reasons that conceptual change is not a matter of interest in workplace learning research and it elaborates on the explanatory power of conceptual change for research on workplace learning in digitalized workplaces. Illustrative references to statements and insights from a small exploratory study in the area of dairy farming will support the argumentation that also comprises thoughts about limitations of conceptual change in the context of workplace learning. The contribution ends with a plea for future research.

CONCEPTUAL CHANGE IN INSTITUTIONAL EDUCATION AS OBJECT OF RESEARCH

"Conceptual change research investigates learning requiring the substantial revision of prior knowledge and the acquisition of new concepts, usually under condition of systematic instruction" (Vosniadou, 2013, p. 11). Conceptual change describes a cognitive achievement that Piaget (1976) described as accommodation: An individual fails to appropriately understand a phenomenon on the basis of their schemata or mental models, and establishes instead a novel mental model that provides an appropriate representation of this phenomenon (Posner et al., 1982). The majority of work on conceptual change stems from science education, but it is nonetheless relevant for other domains of learning, too. The two most recently published edited books about research on conceptual change—that is, the 2nd edition of Vosniadou (2013) international handbook and the collection edited by Amin and Levrini (2018)—mainly comprise literature related to science education and a few contributions related to other domains of school education. It is therefore no surprise that the quoted definition above mentions systematic instruction as a constitutive side condition of conceptual change. The main focus of research on conceptual change always has been and still is students' learning in formal classroom settings. However, following the idea raised by Duit and Treagust (2003), researchers should widen their too-narrow understanding of conceptual change and also consider the full variety of learning opportunities. Both authors argue that conceptual change is indeed related to a much wider range of epistemological and ontological as well as social and affective issues that are not restricted to classroom education only. It therefore becomes plausible that conceptual change may also be a relevant concept that opens up potentials to investigate workplace learning, particularly under circumstances of digitalization of working life.

DIGITALIZATION OF WORKING LIFE

It was already years ago that the European Union defined lifelong learning as a core educational goal in order to cope with the ongoing globalization of markets connected to permanent changes in economy, technology, and society (CEC, 2000). Blue-collar and white-collar workers are required to permanently develop their skills and knowledge to be able to deal with upcoming changes and developments. Apart from this political rhetoric, however, one has to acknowledge that working life in industry, services, and other professional areas has always been subject to changes. Workers have always been required to adapt and modify existing routines as well as to develop new ones in order to develop and maintain their expertise throughout working life. In other words, both change and the requirement to adapt to such change in working life were more the rule than the exception during the last decades. However, the digitalization of working life bears a new quality of change that requires workers' *conceptual change*. The subsequent paragraphs will elaborate on the specific nature of these changes in more detail.

In earlier times, organizational change, and technological development either introduced new tools that made tasks easier or led to revised work processes that required restructured organizations (e.g., assembly-line work or lean production). However, recent digitalization tendencies do not only introduce new procedures and tasks but might more profoundly change how work is organized for many employees (Fischer et al., 2018). Through the introduction of cyber-physical devices (CPD)—that is, all kind of tools that are equipped with sensors and actuators (e.g., a welding robot or a platform floor truck)—which are embedded in cyber-physical systems (CPS)—that is, networks that connect CPDs in a meaningful way—the physical world of work now can be digitally represented and manipulated to an extent that was not yet possible. A welding robot and a platform floor truck exchange data autonomously within the CPS and

coordinate, thus, work processes without requiring any worker's input. A CPS connects the physical world through digital enabled tools (CPDs) to a virtual representation of the organizational processes. It is this virtual representation comprising software algorithms that defines processes conducted by the physical tools. The welding robot as well as the platform floor truck both receive their work orders from the CPS. These digital enabled tools grant a new quality to automation, because (a) they bear the capability to interact with the physical world through sensors and actuators, and (b) they also bear the capability to autonomously communicate between tools, which allows them to manipulate the physical environment. These new opportunities constitute the new quality of changes through digitalization. In fact, a range of scholars argued that these technological advancements allow organizations to further automatize and replace certain tasks and procedures (Frey and Osborne, 2017). The changes connected to these developments as well as their potential effects on human beings are discussed as more drastic and pivotal in the context of work than technological advancements that have been experienced before (Brynjolfsson and McAfee, 2015). The alleged changes will be shortly introduced and discussed in the next few paragraphs.

First, the implementation of CPS changes working tasks because these systems establish new tools that have the potential to replace or merge tasks that earlier human workers were able to do. In addition, both the quality of sensors and actuators, including the data transfer and processing capacities, are developing quickly. Taken together, those systems are able to measure and rapidly adapt to individual human inputs and needs. It might, then, not be the human that defines the scope of action for what the machine can do but the other way around (Gorecky et al., 2014). In addition, certain jobs might be fully taken over by machines. Within the literature different scenarios with regard to these issues are discussed (Düll et al., 2016; Fischer et al., 2018): (1) These systems might replace many tasks and only leave rather simple jobs left for humans that are not cost-effective enough to be automatized. This scenario mostly requires rather low-qualified workers. (2) These systems leave mostly such tasks left for humans that are too complex to be taken over by machines. Such a scenario establishes a labor market that requires mostly high-qualified workers. (3) CPDs and CPSs relieve humans from certain tasks that are menial or dangerous and, thus, allow them to use their physical and cognitive capacities otherwise. In this scenario, humans are needed for work that resembles creative problem-solving that cannot be easily be taken over by machines. It follows that labor markets will probably require highly qualified and skilled workers. (4) Intelligent systems freely adapt to the skill level of workers and thereby help them to realize whatever cognitive and physiological potential are available. In such a scenario, both low- and high-qualified workers might be able to work at very similar workplaces. It is, then, only the level of responsibility that differs with regard to the workers' qualification level.

Second, CPSs induce changes on the organizational level because they alter how labor is distributed between humans and machines. On the one hand, they may replace jobs and tasks, but they will simultaneously establish new ones on the other hand. Since CPDs are equipped with actuators, CPSs can also be used in order to remotely govern work processes without any human being physically present. Responsibilities for human actors arise more strongly in the area of management and controlling of these processes since all working steps can easily and quickly be monitored online through the use of computers. Here it is argued that workers require less knowledge on how to execute concrete tasks related to the manipulation of physical goods. They rather need a broad kind of knowledge on how digitalized processes work (Hirsch-Kreinsen, 2015; Zinn, 2017; Harteis, 2018) as well as competences to operate with digital technology, including competences to extract, select, sort, interpret, and evaluate data that is generated by the CPS (i.e., data literacy, Ridsdale et al., 2015). In other words, the mere nature of a range of jobs will change from execution of tasks toward monitoring and government, and so will the knowledge required to engage in those activities. In addition, new kinds of jobs are created in areas that plan, design, and (technically) maintain these systems.

Third, the main advantage of CPSs is their capability to capture input from the environment and to react autonomously to such input. In interaction with human workers, their operations permanently generate data on human behavior. Hence, employees become public and vitreous in their acting within the organizational setting. This raises issues of data privacy since it is unclear how the abundant data will actually be used alongside the necessary usage to enable CPS to interact with the human workers. Moreover, it is an open question of how individuals emotionally experience such an increased surveillance of their work and how they react to it.

Fourth, a major challenge for employees is that the implemented CPSs are highly likely to remain at least partly opaque for them. For most incumbents, it will be unclear what data is gathered, what data is exchanged between CPDs, and on what rationale the system is making decisions affecting the very nature of their work. Hereby it is not meant that the tools used by employees (e.g., a machine or a computer with its software and hardware) are impenetrable but rather how work itself is organized, as well as why machines and colleagues act in certain ways. Therefore, the danger exists that work becomes more and more a black box. These black boxes might then only be understood by certain specialists, e.g., their developers. Of particular relevance is the fact that developers apply particular assumptions of how users (should) act with or within the digital systems. Hence, CPSs do not only include virtual process models of all interaction opportunities with the physical world but also models of the humans themselves (i.e., a digital anthropology). How these models look, however, might not be accessible for the end users of these systems–i.e., the workers.

The issues discussed above reveal that the changes through digitalization now raise challenges on a new level that go far beyond earlier automation processes. Workers are affected cognitively through changed work tasks and practices, motivationally due to the need of adaption, and emotionally if work is instructed through machines. Particular educational consequences will be discussed within the next paragraph with the goal to emphasize the relevance of conceptual change for learning processes arising from the digitalization of work.

EDUCATIONAL CONSEQUENCES OF THE DIGITALIZATION OF WORK

From an educational point of view, the digitalization of working life raises issues on various levels of thinking, acting, and working. Workers are required to adapt to permanent changes in working tools, techniques, and tasks and they need appropriate preparation. It is one option to develop curricula and to organize formal training programs and seminars. This option is based on the assumption that learning needs are well-known as well as foreseeable, and can therefore be transferred into fitting learning opportunities. However, the discourses on the effects of globalization and digitalization revealed that future development is difficult to predict (Hartmann and Wischmann, 2018). Hence, to count on formal training opportunities seems to be less fitting. If it is impossible to describe future requirements, it is also impossible to develop formal training programs. It follows that the importance of informal forms of learning directly at the workplace and beyond increases. Workers are required to organize learning opportunities autonomously while following their regular working tasks. It is this core competence of self-regulation that stands behind the idea of the aforementioned European educational policy that claims lifelong learning as necessity for maintaining employability (CEC, 2000; Halttunen et al., 2014; Harteis and Goller, 2014).

From a pedagogical point of view, it is similarly important to support workers in developing the skills and capacities required for coping with the challenges of change, as it is important to support workers to maintain their agency and sovereignty of acting. Since Kant (2007) formulated goals of education in times of enlightenment, it is the classical pedagogical goal to support individuals to develop personal and social responsibility, to enable them to make informed decisions and choices in their life course, and to empower them to emancipate themselves from tacit and hidden constraints. In terms of De Charms' (1977) approach of self-perception, the goal of education is that individuals experience themselves not as pawns but as origins. In context of professional learning and development, such individual quality is discussed as work agency (e.g., Eteläpelto et al., 2013). However, a basic prerequisite for work agency is that individuals hold self-regulatory capacities and have a deeper understanding of the circumstances at their workplaces (Goller, 2017). Deliberate choices imply an agent who has at least some knowledge on effects of acting and on control of machines and artifacts. Again, this argument is not about understanding the technological details of software and hardware. It is about a general understanding of how organizational processes at work are structured, who is responsible for what task, and why some things have to be done in a particular way. Without such knowledge, workers quickly become mere pawns subjugated by their environment. It is the CPS that controls their actions and not themselves. In fact, individuals' work agency is particularly at stake when digitalized systems remain black boxes for them or when they have no power to affect what such systems do with them. Nothing is said, yet, of how best to develop those individual qualities. It is just to acknowledge, so far, that an educational perspective on work and workers raises a high level of expectations for workplace learning.

As discussed above, the digitalization of working life raises changes of a novel quality that is not to compare with simple automation as we know it. Automation of work procedures is a well-established kind of change that came along with the early implementation of machines throughout the first industrial revolution at the beginning of the twenty-first century and developed further till the introduction of information and communications technology in working life since the 1970s (Schwab, 2017). Nowadays, however, digitalization will endow the tools varying interaction capabilities and, thus, change tasks, and their organization. Hence, workers either are pure executives reacting on tasks or they are expected to monitor and steer working processes (and machines). Either way, task and job profiles may completely change because of the described developments. Thus, workers may have to develop a new understanding of their tasks and their professional profile, and they may have to develop new skills and knowledge. Therefore, the reflection on educational consequences of digitalization directly leads to issues of conceptual change.

CONCEPTUAL CHANGE AS TRANSFORMATION OF UNDERSTANDING WORK

It is an apparent consequence of the changes of work as described above that workers have to modify their professional schemata and mental models to the extent that digitalization transforms their professional profiles and working tasks. Schemata and mental models are crucial cognitive patterns that allow individuals to appropriately understand work and to act deliberately. Rumelhart et al. (1986) developed a framework for information processing that explains human capacities to understand and deliberately influence the world. In analogy to the two-systems-theory of information processing (Kahneman and Frederick, 2002; Sloman, 2002), Rumelhart et al. claim that the human cognitive system comprises (a) an interpretation network that produces appropriate reactions to input from the world outside, and (b) a model of the world that produces interpretations of what will happen. The interpretation network is connected to the world outside through the individual's sensory system, and the model of the world is related to the interpretation network. Schemata are cognitive entities within the interpretation network that guide pattern recognition. They are constructed by experience and can be activated spontaneously without cognitive effort. Hence, schemata enable humans to spontaneously make sense of a complex situation, e.g., the work environment.

In the majority of cases, people act in familiar circumstances and, thus, mostly succeed in interpreting the world by utilizing their existing schemata—a process that is similar to Piaget (1976) idea of assimilation. However, if people fail in working with or adopting their schemata, the remaining

options are either surrendering or actively reorganizing existing, respectively, developing new mental models—which would mean accommodation in Piaget's terms. A successful establishment of new mental models affords high cognitive effort and results in a new way and quality of understanding work. Even though there are various approaches of conceptual change, there seems to be agreement across these approaches that establishment of new mental models in the sense of accommodation would be counted as conceptual change (Duit and Treagust, 2003; Amin and Levrini, 2018).

The changes through digitalization as discussed above are supposed to raise challenges in working life that requires workers either to change their mental models in the sense of accommodation or that they best manage to cope with challenges through assimilation. Otherwise, they are supposed to fail with the challenges of digitalization. New concepts and mental models can be construed either through social interaction at work (e.g., peers, superiors, experts) or through retrieving codified information from handbooks, professional literature, or the internet.

Different effects of accommodation and assimilations are to be discussed later. The argumentation so far explored changes at workplaces through digitalization that require workers to cope with novel situations and, thus, workplace learning. The circumstances of digitalized workplaces may require a completely novel understanding of work, since CPSs establish new tasks and a new distribution of work. Hence, conceptual change appears to be a relevant issue for workplace learning in digitalized workplaces. However, as argued above, conceptual change seems to be a neglected topic within research on workplace learning; even though a superficial search on literature on the search term "conceptual change" at February 2nd 2019 within relevant databases (ERIC, Fachportal Pädagogik, Google Scholar, PsyIndex, Web of Science, WISO) revealed several thousands of entries, a systematic search of literature within these databases on conceptual change related to "workplace learning" disclosed an amount of only 11 papers, where some of them deal with learning in higher education (e.g., during internships). Facing such a small number of papers, it is to assert that research on conceptual change in workplace learning obviously is still quite scarce. Hence, two questions arise: (1) What are the reasons for this limited amount of research on conceptual change in workplace learning? (2) What is the potential of the concept for understanding and supporting workplace learning in digitalized workplaces?

However, before following these questions, it should be emphasized that work-related changes can also be tackled in a third way that is not directly related to individual accommodation or assimilation. Affected employees could indeed realize that their shared work knowledge (see also Kimmerle et al., 2010) is in conflict with the new work practices. In such a case, workers might engage in collective agency (Bandura, 2000) and jointly refuse or rebuff technology (e.g., Vähäsantanen, 2013). It is especially such efforts that simultaneously change work practices and lead to some kind of co-construction of knowledge. However, the focus of this article is on (individual) cognitive change. That is why the social-cultural perspective on externally induced change at work won't be considered here.

Question 1: What Are the Reasons for a Neglect of Conceptual Change in Research on Workplace Learning?

The reasons for the lack of conceptual change consideration in research on workplace learning may be found both in research on school learning and studies on workplace learning. Generally, scholars concerned with school education, teacher education, and workplace learning consider themselves members of different research communities with sparse overlapping, even though they share the common umbrella to be interested in issues of learning and instruction.

The conceptual change research community refers to Thomas S. Kuhn as the one who introduced the relevance of conceptual change by explaining the differentiation of scientific theories and their fundamental change by time (Kuhn, 1962). Hence, the origin of the idea of conceptual change can be traced back to the philosophy of science. Consequently, researchers addressing such phenomena of radical change in belief systems and mental models focused on the shift from naïve concepts to scientific concepts. It is therefore not surprising that school and higher education contexts are the primary fields for observation, and the vast majority of (empirical) research occurs in those settings. From this perspective, only very few incentives existed for scholars involved in conceptual change research to widen their observations to adults in working life. Possible explanations may be that they did not see relevance—since formal learning settings are still at the core of educational science—or that this neglect simply reflects the rich challenges to organize empirical studies in work settings (e.g., Rausch, 2011).

The research community concerned with workplace learning is quite diverse. On the one hand, there is a huge body of research that follows the socio-cultural approach of learning and, thus, majorly focuses on social processes and social influences on learning (Hager, 2011). Those researchers describe learning as individuals' trajectory toward the center of a particular community of practice (e.g., Lave and Wenger, 1991). Following Billett (2008), an interpretation could be that knowledge is something that dominantly exists on the social plane and is being negotiated between professional actors. Of course, there are sociocultural approaches of learning that also consider individual and cognitive issues of social learning (e.g., Marshall, 2008; Billett and Choy, 2013; Ley et al., 2019), but they all interpret knowledge structures as internalized cultural knowledge patterns. There is less focus put on individual mental efforts than in the discussion about conceptual change. On the other hand, many researchers on workplace learning follow cognitive approaches of learning that refer to expertise research which focuses on the influence of experience on the development and modification of knowledge structures (e.g., Gruber and Harteis, 2018). Within this theoretical account, conceptual change has not been a concept that attracted researchers yet. Changes within cognitive structures are instead discussed using theories like Adaptive

Control of Thought by Anderson (1982, 1993), Dynamic Memory by Kolodner (1983, 1993), or Knowledge Encapsulation by Boshuizen and Schmidt (1992, 2008). Additionally, many scholars address cognitive and constructivist issues of social and individual influences on learning at work and learning for work, but they work with alternative concepts reflecting individual knowledge development. A possible explanation may be that learning at work does usually not follow a worked-out curriculum but occurs in a rather informal way (which does not imply that learning at work is free from many structuring elements; Billett, 2011, 2014). Moreover, work-related concepts are not as distinct and well-defined as concepts in science are. Therefore, scholars interested in workplace learning might face problems of how to define and agree on the desired endpoints of conceptual change in work contexts. This obviously makes it much more difficult to empirically investigate workers' conceptual change. However, remembering the plea for a wide understanding of conceptual change raised by Duit and Treagust (2003), it is emphasized that conceptual change neither requires a curriculum nor instruction.

Question 2: What Is the Potential of the Concept of Conceptual Change for Understanding and Supporting Workplace Learning in Digitalized Workplaces?

Digitalization of work leads to changes in working tasks, working tools, and work organization. Depending on the radicalness of digital transformation, workers are required to acquire new skills and to modify their knowledge. The concept of conceptual change can help to understand the way workers adapt to requirements of digitalization in their work environments. In order to consolidate this claim, three rough scenarios can be distinguished, of which McAfee and Brynjolfsson (2017) assume that a mix of all three will become reality:

- *Replacement.* This scenario describes digitalization of work as a complete replacement of human tasks by machines. Knowledge and skills required for particular tasks become obsolete, and the machine can be considered a new tool that workers have to operate.
- *Enrichment.* This scenario describes work settings that modify human tasks by integrating machines into operating sequences. Existing mental models thus need to be modified, and new ones need to be added and integrated into the established knowledge structures.
- *Establishment.* This scenario describes the implementation of new work procedures through machines. They require the development of completely new mental models. That is why established knowledge structures may become obsolete.

The concept of mental models (Vosniadou and Brewer, 1992; Nersessian, 2013) is appropriate to describe a worker's representation of their professional job profile. The implementation of digital machines at workplaces bears both cognitive (i.e., epistemological and ontological) and social and affective issues. As most workplaces require social interaction (as well as man-machine interactions), workers cope with changes through participation in social interactions that generate affordances and constraints which shape their understanding of their workplaces and working tasks (Billett, 2004).

Given that workers learn to cope with the ongoing digitalization, the question arises of which kind of mental models they develop. In a rough distinction, two analytically extreme points can be identified that apply for all three scenarios introduced above. On the one extreme, workers take the digital machines for granted and use them the way they were instructed. In this case, the mental model of the digitalized machine and working task can be characterized as black box. Workers just integrate the machine into their existing mental model—in Piaget's terms, assimilation would have happened, without a deeper understanding for the mechanism and functionality of the machine. On the other extreme, workers become unsatisfied with their lack of knowledge and construct a mental model of the machine that reflects a deeper understanding of mechanisms and functionality. This case would then characterize a conceptual change or accommodation in Piaget's terminology. From an educational perspective, the latter option surely is the preferred one, since workers keep their work agency this way. The former option, however, bears the risk that workers lose their agentic capabilities and are, therefore, not any more able to exert control within their work environment. In reality, neither of these extreme points might be realized. It is more realistic that workers are located somewhere between both extrema. However, this analytical continuum helps to understand how workers might cognitively deal with changes caused in the context of digitalization.

It is exactly the strong explanatory power of the construct conceptual change to characterize a deep quality of workplace learning that leads to an understanding of digitalized workplaces that allows workers to act in a competent and responsible way. If workers in digitalized workplaces fail to conceptually change their mental models, they may be able to operate machines but not to steer and monitor digitalized processes. In fact, workers then become human CPDs that are largely controlled by the CPS in the same extent as their technological counterparts (i.e., other machines within the CPS). This, however, would be a vision that fully contradicts the pedagogical idea of individuals that maintain their agency and sovereignty of acting (Kant, 2007). Instead, workers tend to become subjugated by digital forces rather than being able to make their own informed choices that then are being used as foundation for self-determined actions.

EXPERIENCES FROM A SMALL EXPLORATORY FIELD STUDY

The theoretical arguments presented in this paper are now illustrated through insights from an interview study with farmers that has been fully described elsewhere (Goller et al., 2020). The agricultural sector is that part of the economy that started with digital transformation already 20 years ago and that is one of the domains with the highest digital saturation (Walter et al., 2017; Shamshiri et al., 2018). It suggests itself for investigating effects of digitalization in terms of conceptual change.

Among other themes, the shape and development of farmers' mental models who changed from traditional farming modes toward fully automated digital systems were investigated by Goller et al. (2020). To be more concrete, the study focused on dairy farms working with milking robots as well as digitalized feeding, cattle-monitoring, fencing, and oestrus identification systems and applied semi-structured interviews with ten farmers. All these farmers experienced digitalization-induced change themselves. The interviews focused on farmers' mental models of their work as well as the modification of these mental models through digitalization. The implementation of these systems completely altered the farmers' working tasks and their way of treating cattle. In times of manual ranching, farmers had daily physical contact with their livestock, whereas nowadays digitalized cowsheds do not require physical contact most of the time.

Farmers describe that task profiles radically changed through digitalization. Most obviously, the capability to operate computer systems that control feeding, milking, and nurturing cattle as well as the maintenance of the used CPDs (milking roboter, sensors worn by the cattle, feeding machines) raised new skill demands. Consequently, other competences connected to traditional working methods that are now taken over by the machines in use and that have been connected to manual labor increasingly lost their importance. In terms of conceptual change and the development of mental models, a few interesting observations could be made.

First, all farmers reported the emerging need to be able to interpret a range of data coming from different sensors that did not exist in the context of traditional dairy farming. Here it is not only necessary to interpret data but also to select particular values from a rich dataset and critically evaluate their information content. Interestingly, a few farmers emphasized that it requires both a good mental model of the digital system (e.g., What data is provided? Where does the data comes from? How reliable is the data?) and a good mental model of the cattle as such (e.g., How do particular illnesses manifest themselves into sensor data? What is the tolerance range of certain values? Are values biased because of medication that animals become?). Problems especially occur if those mental models are not well-connected because provided data cannot then be reliably interpreted and work would become more error prone. The development of the digital mental model as well as the connection of both originally separated mental models can be classified as conceptual change since it requires much more than mere assimilation of new knowledge. Most interviewees seem to have managed this cognitive endeavor.

Second, all interviewees reported that the introduction of the digital systems allows them to be more flexible with their time. Traditional dairy farming required them to milk cattle twice a day in the morning and the evening. Because of the automation of the milking processes, it is no longer required that farmers work at this fixed time schedule. And although all farmers described this a positive development, they also reported the new emerging demand of being able to self-organize their working days. In other words, farmers need to reorganize their mental models of daily work structure in a way that is not based on the needs of the animal. In this context, the finding has been that especially younger farmers managed to make this change more successfully than older farmers.

Third, most interviewees showed a general understanding of the CPS as well as the different CPDs in use on their farm. They were able to explain what the different parts are doing, how they work together, and what technological constraints have to be considered in day-to-day work. At the same time, however, all but one (an electrician by additional training) explained that they have no deep understanding of the technology in use, so if it comes to more fundamental maintenance issues or malfunctions, they depend on assistance from technicians. In other words, although the digital systems in use are not complete black boxes for them, they lost some of their work agency because they cannot as independently react as in the context of traditional farming. This is a direct effect of an ongoing division of labor.

Fourth, although all interview partners seemed to have developed a general understanding of the technology at their farms, differences between the farmers were also detectable. Some of the farmers described the system mostly based on crucial and output values or work with (naïve) analogies (e.g., assigning human characteristics to the digital systems—"the computer is on the blink," "the system's in bad mood"). Others instead used far more elaborate terminology in their descriptions that indicate a richer and more fitting mental model of the technology. Interestingly, all affected interview participants' development can be described as quite prototypical for the farming domain: growing up at the parental farm, experiencing a traditional job profile (i.e., manual and technical agriculture), but getting acquainted with digital technology and natural science through vocational education and training, and finally investing in the implementation of those systems at the parental farm and thereby actively transforming their work requirements. During this transition, these farmers underwent the classical way of conceptual change in institutional education from pre-scientific to scientific mental models: Their knowledge transformed from initially naïve mental models toward scientific and IT-related concepts of dairying.

Based on this brief description, it should become evident that ideas of conceptual change are indeed useful to describe professional development of working adults within the context of as well as beyond digitalization. It requires, however, more empirical work to show whether this proposition really holds.

PLEA FOR FUTURE RESEARCH

The challenges of digitalization, as discussed above, may raise circumstances of opaque steering processes that are controlled by computer algorithms at many workplaces and in many economic sectors (banking, finance, production plants, etc.). If these challenges require skilled staff which do not only operate within an arrangement of digital systems but who also understand processes and who are able to intervene and control these systems, workers need to be supported to develop the necessary skills and knowledge. This might occur through vocational education, further education, or workplace learning.

Anyway, the educational as well as working environments need to provide supporting circumstances for such development. It is the broad topic of learning culture that describes characteristics of organizations that provide such supporting circumstances (e.g., Popper and Lipshitz, 2000; Marsick and Watkins, 2003).

This does not mean that a neoliberal standpoint is advocated here in which the burden of adaption to technological changes is only on the employees. It is explicitly acknowledged that organizational changes should always be carefully planned and outlined with the human perspective explicit in mind. This surely is an issue that cannot be tackled from a conceptual change perspective. Instead, research is needed that investigates how organizations and workplaces can be developed in such a way that they meet the needs and characteristics of their employees. This is especially a question of the anthropology that shapes technology driven change (Harteis, 2018). It is important to design human-centered digital systems that consider humans not as disturbance term but as individuals that interact with technical systems.

We nevertheless think that even in cases where new technology is introduced in a way that deeply considers the needs and characteristics of the affected employees cognitive individual adaption will be necessary. Thus, we want to argue here that conceptual change is an appropriate construct to explain how employees cognitively cope with new challenges at work through workplace learning. Only if workers succeed in accommodating novel mental models of their digitalized workplaces, they develop skills and knowledge to master the digital transformation competently and responsibly. Hence, the construct of conceptual change is of particular relevance from a pedagogical perspective that claims emancipation and responsibility as major goals of education.

However, for future research, particular challenges arise that are unsolved so far. Firstly, it is difficult to precisely define criteria for successful conceptual change. Digital transformations may appear in different occurrences that may require particular skills and capacities. Hence, it may be difficult to define a general level of skills and capacities that enables workers to keep control on the working tools. Secondly, in contrast to school settings that usually imply learners with similar levels of prior knowledge, workplaces bring together workers with very different levels of skills and capacities. Research on conceptual change in work contexts probably has to consider the potential heterogeneity of prior knowledge in particular. Thirdly, it is a specific quality of digital man-machine interaction that computer systems may assemble virtual realities that may suggest workers putatively to hold control. Hence, it appears possible that workers accommodate new knowledge and proceed with conceptual change successfully but still fail to control the digital systems. Finally, development of information and computer technology occurs quickly so that further development is difficult to predict. Algorithms and software solutions increasingly become more complex. Therefore, research on digitalization of work requires interdisciplinary research approaches—otherwise, particular specification of digital transformation may remain neglected. However, interdisciplinary research requires particular efforts to generate commonly shared understanding between the disciplines, because different disciplines (e.g., robotics and education) bear different understanding of the same term (e.g., learning). The challenges discussed here arise from the idea to consider conceptual change as a relevant construct for investigating workers' learning in digitalized workplaces. Such research is necessary, because conditions of workplaces differ from conditions in school settings. The current body of research on conceptual change does not provide insight on the issues raised here.

AUTHOR CONTRIBUTIONS

All the authors developed the theoretical frame for this article. CH developed most of the text. MG contributed to the text development and integrated the experiences from the field. CC contributed to the text development and to the interpretations of the field experiences.

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