Management international
International Management
Gestiòn Internacional

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Repensar la transmisión intergeneracional del conocimiento en la era de la Industria 4.0

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Volume 27, Number 6, 2023

Le management des connaissances à l'épreuve des nouveaux « objets » de la gestion du XXI[e] siècle
Knowledge management put to the test the new "objects" of 21st-century management
La gestión del conocimiento a prueba de los nuevos "objetos" de la gestión del siglo XXI

URI: https://id.erudit.org/iderudit/1108845ar
DOI: https://doi.org/10.59876/a-64xf-j58z

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Publisher(s)

HEC Montréal
Université Paris Dauphine

ISSN

1206-1697 (print)
1918-9222 (digital)

Explore this journal

Cite this article

Kuyken, K. & Schropp, R. (2023). Rethinking intergenerational knowledge transmission in the era of Industry 4.0. *Management international / International Management / Gestiòn Internacional*, *27*(6), 44–56. https://doi.org/10.59876/a-64xf-j58z

Article abstract

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ABSTRACT

Inspired by a human-centered perspective on technological changes of work, this paper presents a theoretical effort of bridging two distinct fields: Industry 4.0 and intergenerational knowledge transmission. It contributes to the literature on knowledge management with an analysis of how Industry 4.0, as one of the new objects of the 21st century management, challenges and transforms practices of intergenerational knowledge transmission. Based on a narrative literature review, we identify four facets representing the main managerial considerations on Industry 4.0, discuss their implications for intergenerational knowledge transmission and outline avenues for future research.

Keywords: Intergenerational knowledge transmission, knowledge management, Industry 4.0, human-centered perspectives

Résumé

Inspiré par une perspective centrée sur l'humain quant aux changements technologiques du travail, cet article présente un effort théorique de rapprochement entre deux domaines distincts : l'Industrie 4.0 et la transmission intergénérationnelle des connaissances. Il contribue à la littérature sur la gestion des connaissances en analysant comment l'Industrie 4.0, en tant que nouvel objet de la gestion du 21e siècle, remet en question et transforme les pratiques de transmission intergénérationnelle des connaissances. Sur la base d'une revue de littérature narrative, nous identifions quatre facettes représentant les considérations managériales principales sur l'Industrie 4.0, discutons de leurs implications pour la transmission intergénérationnelle des connaissances et proposons des pistes de recherches futures.

Mots-Clés : transmission intergénérationnelle des connaissances, gestion des connaissances, Industrie 4.0, perspectives centrées sur l'humain

Resumen

Inspirado en una perspectiva centrada en el ser humano sobre los cambios tecnológicos del trabajo, este artículo presenta un esfuerzo teórico para conectar dos campos distintos: La Industria 4.0 y la transmisión intergeneracional del conocimiento. Contribuye a la literatura sobre la gestión del conocimiento con un análisis de cómo la Industria 4.0, como uno de los nuevos objetos de la gestión del siglo XXI, desafía y transforma las prácticas de transmisión intergeneracional del conocimiento. Basándonos en una revisión narrativa de la literatura, identificamos cuatro facetas que representan las principales consideraciones de gestión sobre la Industria 4.0, discutimos sus implicaciones para la transmisión intergeneracional del conocimiento y esbozamos vías de investigación futura.

Palabras Clave: Transmisión intergeneracional del conocimiento, gestión del conocimiento, Industria 4.0, perspectivas centradas en el ser humano

Pour citer cet article : Kuyken, K. & Schropp, R. (2023). Rethinking intergenerational knowledge transmission in the era of Industry 4.0. *Management international*, 27(6), 44-56.
DOI: https://doi.org/10.59876/a-64xf-j58z

The manufacturing sector is currently being transformed by a profound digital shift and an intensification in the use of emerging technologies which is commonly summarized under the term "Industry 4.0" (Kagermann, Wahlster, & Helbig, 2013). So far, a techno-centric stance on the topic is dominating while the existing "human-centered" body of research still needs to shed light on work-related implications, notably for human workers and their knowledge (Schneider, 2018). Building on this emerging stream of literature, we attempt to provide a human-centered perspective on Industry 4.0 by reflecting on an original managerial aspect: the role of generation-specific knowledge and new practices of intergenerational knowledge transmission. The intensification of technological use requires permanent knowledge acquisition as well as a dynamic combination of diverse forms of knowledge coming from different generations, which makes the study of intergenerational knowledge transmission in the context of Industry 4.0 highly relevant. Although numerous scholars and practitioners have developed approaches based on the concept of knowledge transfer (Beazley, Boenisch, & Hardan, 2002) or knowledge retention (Levy, 2011) over the last three decades, research on intergenerational knowledge transmission in the era of Industry 4.0 is still in its infancy. Based on these reflections, this paper contributes to the literature of Knowledge Management (KM) in two ways: First, we provide a fine-grained analysis of possible implications and considerations of Industry 4.0 for intergenerational knowledge transmission, including new practices. Accordingly, we establish relevant connections between two rather disconnected research fields (Industry 4.0 and intergenerational knowledge transmission) which go beyond the polarized discussion on the future of human knowledge where scholars argue either in favor of specific competencies or human-less factories. Second, based on this analysis, we formulate questions and avenues for future research in the field of KM, Industry 4.0 and intergenerational knowledge transmission. What is more, we contribute to the literature on Industry 4.0 by developing a novel, human-centered definition of the term. Hence, in response to the call for papers for this special issue, this narrative review is oriented by the following research question: When considered as a new object for KM, how does Industry 4.0 transform intergenerational knowledge transmission? The remainder of this paper is structured as follows. First, we present the state of the art on the two research fields and point towards relevant interrelations. Second, we outline the methodology used for this paper. Third, we present the findings in the form of four facets and then link these to aspects related to knowledge management in Industry 4.0. Fourth, we discuss the implications of each facet for intergenerational knowledge transmission and formulate avenues for future research.

Literature review

Dominance of a techno-centric stance of Industry 4.0

Current research conceives Industry 4.0 most often as a "new type of industriali[s]ation" (Kagermann *et al.*, 2013, p. 5) allegedly capable of boosting manufacturing efficiency and productivity through the intensive use of new technology at all production stages in modern organizations *(ibid.)*. Since the first apparition of the term at the Hanover fair in Germany in 2011, it has aroused much interest among researchers, but also among policy makers, consultants or diverse interest groups from the industry (Lindner, Ludwig, & Amberg, 2018; Pfeiffer, 2017). Despite the increasing scientific output, Industry 4.0 is often ill-defined and insufficiently distinguished from earlier, but similar debates on technology. It is argued that Industry 4.0 differs from the three previous technological revolutions by its combination of different emerging technologies in the physical, digital, and biological domains (Lindner *et al.*, 2018)—also called "technological innovations related to digitalization" (Bootz, Michel, Pallud, & Monti, 2022)—as well as its potential to integrate humans, machines, and objects across the whole value chain (Schwab, 2016). Hence, literature presents Industry 4.0 mainly from a techno-optimistic and techno-utopian perspective (Hirsch-Kreinsen, Ittermann, & Niehaus, 2018). From this viewpoint, Industry 4.0 consists in a new way of organizing the means of production, characterized by greater adaptability to client needs by means of a flexible and modular production floor as well as connected devices which operate autonomously in real time and make decisions based on data (Julien & Martin, 2021; Kohler & Weisz, 2016) and interconnected platforms frequently grouped under the terms Internet of Things (IoT) as well as cyber-physical systems (CPS) (Kagermann *et al.*, 2013).

Despite the abundant tech-oriented literature, critical voices raise concern that Industry 4.0 represents a current "hype" (Pfeiffer, 2017), pushed by interest-driven opinion polls (e.g., by consulting firms) (Mertens, Barbian, & Baier, 2017), which has resulted in a highly scattered and fragmented literature (Meindl, Ayala, Medonça, & Frank, 2021) and insufficient cumulative and interdisciplinary research (Mertens *et al.*, 2017). Most importantly for our study, empirical evidence from management is still rather scarce or largely influenced by insights from manufacturing (Agostini & Filippini, 2019). Notably, there is currently a lack of studies considering fundamental human-centered aspects—especially social and interpersonal practices such as intergenerational knowledge transmission—as is often the case when the fascination for technology is dominating the public debate (Hirsch-Kreinsen *et al.*, 2018).

Human-centered considerations of Industry 4.0 and their link to intergenerational knowledge transmission

While a techno-utopian view on Industry 4.0 is prevailing in the literature, the role of human workers remains a major concern for management scholars. Three aspects which are widely discussed in this regard point towards a strong and relevant link to research on intergenerational knowledge transmission: the future of human skills, human-machine interactions, and worker empowerment.

First, "human-centered" research is often confined to controversies about the "future of work" (Trompisch, 2017) and the "future of employment" (Frey & Osborne, 2017). While some studies predict a general process of upskilling, others warn of a polarization in high-qualified and low-qualified jobs (Hirsch-Kreinsen *et al.*, 2018). Second, human workers

are part of considerations on future human-machine interaction. The central propagated idea is that humans and technology must work in complementarity, meaning that tasks are allocated either to workers or machines, depending on their strengths and weaknesses (Kopp, Dhondt, Hirsch-Kreinsen, Kohlgrüber, & Preenen, 2019). From this perspective, the human worker is expected to supervise and behave correctly and rapidly in any unforeseen situation (Pacaux-Lemoine, Trentesaux, Zambrano, & Millot, 2017), which leads to rising expectations for "augmented humans" (Julien & Martin, 2021). A third aspect addresses the future opportunities of greater employee empowerment, responsibility, and participative work designs (Kagermann *et al.*, 2013; Kopp *et al.*, 2019) and therefore potential agentic elements. For example, scholars discuss new organizational forms like swarm organizations and decentralized work designs (Franken & Franken, 2018) or dislocation of decision-making power from management to employees (Kopp *et al.*, 2019).

Interestingly, these three aspects related to KM have not yet been empirically investigated from a perspective focusing on generations, although they are likely to concern aspirants, apprentices, entrants, junior, middle-aged, and senior workers alike. First theoretical reflections linking Industry 4.0 and generations exist: With new opportunities for human-machine interaction, competency development and longer working lives due to flexible career designs, scholars present Industry 4.0 as one possible response to the demographic change in Germany (Kagermann *et al.*, 2013). From a sociologist perspective, Pfeiffer (2016; 2017) observes the increasing role of human expertise which is accumulated over the years and therefore involves several generations. We claim that a stronger link between this kind of research and the literature of KM and intergenerational knowledge transmission offers an essential opportunity to strengthen the human-centered perspective on Industry 4.0.

Fueled by these reflections, a stronger human-centered orientation on Industry 4.0 in management research is indispensable to stimulate a scientific debate which is not limited to the effects of technological objects but does justice to sociological dynamics in modern organizations in all its facets.

The Field of knowledge management and its evolution

The field of KM has emerged in the mid-1990s in the context of the "knowledge economy" (Foray, 2009) which is based on the neo-economic idea that knowledge is the principal source of value creation (Easterby-Smith & Lyles, 2011). Since then, KM has become polyphonic since it regroups a variety of approaches and perspectives (Baskerville & Dulipovici, 2006), such as the resource-based view (Kogut & Zander, 1992; Prahalad & Hamel, 1990), or the social anthropology of learning (Brown & Duguid, 1991; Lave & Wenger, 1991). One major premise of existing theoretical foundations is that people in organizations are human carriers of knowledge which can manifest itself in different forms (Nonaka & Takeuchi, 1995). Notably, scholars agree that KM cannot be limited to explicit, formalized knowledge but has to be studied in combination with tacit, implicit, and experiential knowledge (Foray, 2009; Polanyi, 1967). While explicit knowledge can be transferred from one person to another, tacit knowledge is based on very individual experiences and contextual factors, and thus anchored in the memory of actors (Tsoukas & Vladimirou, 2001). In the same vein, KM researchers have been concerned very early on with the reconciliation of the technological means to capture explicit knowledge and its human dimension which is "deeply social in nature" (Thomas, Kellogg, & Erickson, 2001, p. 881).

Intergenerational knowledge transmission seen from a human-centered knowledge management perspective

As part of the KM field, research on intergenerational knowledge transmission has also inherited a polyphonic character. The focus on generations and their knowledge emerged progressively since the early 2000s, due to a managerial challenge: the so-called "baby-boomers" were close to retirement, calling for measures to transfer their knowledge to younger workers to prevent knowledge loss (De Long & Davenport, 2003). As a response to this organizational challenge, technology-centered approaches on the subject, focusing on knowledge preservation and capitalization—notably through information systems (Ermine, 2010; Levy, 2011) and rooted in the technological perspective on KM (Mitchell, 2007)—dominated scholarly work in the first decade of this millennium. While recognizing the strengths of such a perspective, several scholars however advocated a human-centered perspective and highlighted the flaws of techno-centered studies, such as an insufficient focus on (seniors') tacit knowledge (Ebrahimi, Saives, & Holford, 2008), the need to concentrate on social factors such as generational relations (Joshi, Dencker, Franz, & Martocchio, 2010; North & Fiske, 2015), cultural particularities (Kuyken, Ebrahimi, & Saives, 2018) and on the collective at work rather than on individual interaction with information systems (Schmidt & Mühlfeld, 2017). This body of literature picks up the social anthropology perspective of KM which had already provided key reflections on generations and their knowledge in the early 1990s. Scholars argued that generational and situated knowledge is shared through communities of practice (CoPs) which represent social learning spaces (Brown & Duguid, 1991; Lave & Wenger, 1991). In this perspective, younger workers joining the organization can then share knowledge with their senior colleagues through "legitimate peripheral participation" (Lave & Wenger, 1991).

When it comes to studying KM from this point of view, it should be noted that despite the variation in the definitions of knowledge "transfer", "sharing" and "transmission", these terms are frequently interchanged in extant literature (Harvey, 2012). The most dominant view of intergenerational knowledge transmission implies a unidirectional vision of the latter, where senior employees transfer their knowledge to their younger colleagues (DeLong & Davenport, 2003; Levy, 2011). There is however a recent tendency towards a bidirectional view which emerged based on Tempest' view on reciprocal intergenerational learning (2003), and in line with the increasing number of studies adopting managerial and social perspectives. Scholars advocating this view take the social context into consideration and portray intergenerational knowledge transmission as a fluid and reciprocal process (Gerpott, Lehmann-Willenbrock, & Voelpel, 2017; Kuyken *et al.*, 2018). Acknowledging this more dynamic view, we prefer using the term of intergenerational knowledge *transmission* which is, therefore, defined as a dynamic and interactive process of mutually sharing tacit and explicit knowledge between two or more individuals of different generations (Kuyken *et al.*, 2018). Research rooted in such perspective has led to several contributions: A first notable contribution is a deeper understanding of generations' tacit knowledge (Ebrahimi *et al.*, 2008; Leonard & Swap, 2005; Nonaka & Toyama, 2007). Furthermore, scholars have identified shared knowledge forms (Gerpott *et al.*, 2017), team dynamics (Gerpott & Fasbender, 2020) and challenges (Schmidt & Mühlfeld, 2017), and developed a taxonomy of intergenerational knowledge transmission practices, including mentoring, expert interviews and multi-generational training (Kuyken *et al.*, 2018). Despite the contributions this bidirectional perspective on intergenerational

knowledge transmission has offered, further research is needed (Gerpott *et al.*, 2017). According to Rondi and colleagues (2021), the view on intergenerational knowledge transmission is still oversimplified, especially given the digital transformation of organizations. The present endeavor aims to contribute to this stream of research.

Methodology

We conducted a narrative literature review on the managerial aspects of Industry 4.0 to provide an overview of the major tendencies of the intersection of the two research fields. Given the scarcity and fragmentation across research fields of the emerging literature on Industry 4.0 adopting a human-centered perspective (Agostini & Filippini, 2019; Meindl *et al.*, 2021) as well as the absence of research grounded in the generations' literature, a narrative literature review appears to be an appropriate methodological approach for our study. It can be defined as "comprehensive narrative syntheses of previously published information" (Green, Johnson, & Adams, 2006, p. 103) and tends to focus on general debates in the literature (Ferrari, 2015) with the goal to offer an understanding of existing work, potential gaps and future perspectives and research avenues on a specific research topic (Cronin, Ryan, & Coughlan, 2008; Frank & Hatak, 2014). Hence, the goal is not to provide an exhaustive account of the state of the art on the managerial considerations around Industry 4.0, nor to seek any generalization on the management literature on Industry 4.0 (Paré, Trudel, Jaana, & Kitsiou, 2015; Tranfield, Denyer, & Smart, 2003). Moreover, to counter steer potential researcher confirmation bias (Green *et al.*, 2006) and the reproach of lacking "critical appraisal" (Frank & Hatak, 2014), we point to the shortcomings, weaknesses, and discrepancies of the existent literature body (Paré *et al.*, 2005). This critical and reflective stance allowed us to go beyond a mere descriptive account of the selected literature (Tranfield *et al.*, 2003) and to identify critical conceptual elements which deserve a deeper theoretical reflection.

Finally, while most reviews in the management literature are narrative (Tranfield *et al.*, 2003), it is a common practice for this type of review not to provide an explicit definition of the review process (Paré *et al.*, 2015). To add clarity to the methodological reflections underlying the review (Ferrari, 2015) as well as to respond to the frequent criticism of subjectivity (Paré *et al.*, 2015) and the pejorative qualification of narrative literature reviews as "unsystematic reviews" (Green *et al.*, 2006), we provide a detailed and structured overview of our research process in Appendix A. This process consisted of a rigorous, long-term search over a period of eight months in 2021 during which both authors regularly scanned the management literature on Industry 4.0 with a particular focus on human-centered and KM-related elements. Given our interest in the human-centered perspective, we paid attention to broad keywords like "organizational impact", "knowledge management" as well as concepts related to KM like competencies, skills, training, human factor, etc. Considering broad conceptual terms is a legitimate strategy for narrative literature reviews to evaluate the validity of the research process (Frank & Hatak, 2014). We first paid attention to the use of these keywords in the titles of the selected texts before we read the abstracts in detail. As a last step to determine if the paper could be considered as human-centered, we scanned the literature review as well as the results and the discussion sections to identify its conceptual focus and contribution. After having applied different selection and exclusion criteria (see Appendix A), a total of 36 texts (papers, books, book chapters, conference proceedings, reports) was selected and analyzed regarding emerging managerial considerations for KM and intergenerational knowledge transmission in the context of Industry 4.0. To live up to the claim that the review is an "integrative endeavo[u]r" (Frank & Hatak, 2014, p. 111) showing how the selected pieces of the literature fit together, we synthesize in the next section the main results of the selected texts with a particular focus on Industry 4.0 and KM.

Findings

Linking managerial considerations of Industry 4.0 to intergenerational knowledge transmission

Four main conceptual facets emerged from the selected literature, illustrating how Industry 4.0 is understood and conceptualized from a managerial perspective. Those are (1) Visionary paradigm; (2) Digitalization of the industry; (3) Interconnected networks; (4) Control by smart and autonomous devices. We first present each facet going from the most (1) to the least (4) general facet before we outline aspects related to KM which are highlighted in the analyzed literature.

Facet 1: Visionary paradigm

Facet 1 represents the overall meaning of Industry 4.0 used by both its proponents and critics. Most of the analyzed texts view Industry 4.0 as a vision and paradigm, implying that it is not yet part of the organizational reality but rather a way of thinking about the future. The authors speak of a "new productive paradigm" (Foresti & Varvakis, 2018), "data-driven paradigm" (Capestro & Kinkel, 2020) or even a "paradigm shift" (Flores, Xu, & Lu, 2020; Kagermann *et al.*, 2013). In the same vein, other scholars point to a "future project" (Wilkesmann & Wilkesmann, 2018), a "vision of the future" (Calış Duman & Akdemir, 2021) as well as a "technological ambition" and "new industrial imagination" (Kohler & Weisz, 2016).

Implications for KM. If Industry 4.0 is really going to introduce a "paradigmatic shift" in contemporary organizations, the latter must rely on employees who are able to see the "big picture" (Karacay, 2018). This vision can be developed through (1) creating learning opportunities which are separated from the core business (Schneider, 2018), such as learning factories (Abele, Metternich, & Tisch, 2019; Schallock, Rybski, Jochem, & Kohl, 2018) or scenario-based learning activities (Erol, Jäger, Hold, Ott, & Sihn, 2016), and (2) involving employees in the design, development and implementation processes of new technologies (Trompisch, 2017). Moreover, organizations seek to integrate a wide spectrum of different types of human knowledge, leading to a higher complexity (Harteis & Fischer, 2017; Prifti, Knigge, Kienegger, & Krcmar, 2017) and broader scope of tasks (Agostini & Filippini, 2019; Schneider, 2018) and therefore to increasing requirements regarding human knowledge (Kagermann *et al.*, 2013; Karacay, 2018). More precisely, the demands on workers for continuous learning (Flores *et al.*, 2020), lifelong learning (Prifti *et al.*, 2017; Thornley, Carcary, Connolly, O'Duffy, & Pierce, 2016), interdisciplinary learning (Karacay, 2018; Trompisch, 2017) as well as discarding obsolete knowledge (Ansari, 2019) are very high. What is more, scholars argue that current employees need to be reskilled while younger generations need to be prepared for the changing skill requirements (Karacay, 2018). Experts who can manage critical incidents (Harteis &Fischer, 2017; Maier & Reimer, 2018) and solve problems (Kohler & Weisz, 2016;

Prifti *et al.*, 2017)—especially ad hoc (Agostini & Filippini, 2019)—are arguably of central importance for realizing the vision of Industry 4.0 (Pfeiffer & Suphan, 2018).

Facet 2: Digitalization of industry

Industry 4.0 is mainly discussed as a new combination of the traditional sector of manufacturing and information and communication technology (ICT), for example by describing it as the "merge of the production with the ICT" (Foresti & Varvakis, 2018) or the "marriage between mechanical industry and the Internet" (Kohler & Weisz, 2017), the "digitalization of the manufacturing sector" (Capestro & Kinkel, 2020) or similar other terms (Calış Duman & Akdemir, 2021; Erol *et al.,* 2016; Roblek, Meško, & Krapež, 2016; Schneider, 2018). Two technologies are seen as two main drivers of Industry 4.0 (Abele et *al., 2*019; Sopadang, Chonsawat, & Ramingwong, 2020): cyber-physical systems (CPS) (e.g., Harteis & Fischer, 2017; Kohler & Weisz, 2017; Meindl et *al., 2*021; Prifti et *al., 2*017; Roblek et *al., 2*016; Shamim, Cang, Yu, & Li, 2017) and the Internet of Things (IoT) (Agostini & Filippini, 2019; Capestro & Kinkel, 2020; Erol et *al., 2*016; Pfeiffer, 2017; Scheer, 2020). CPS are production systems connected to the Internet and able to communicate with each other (Scheer, 2020) while IoT refers to the connection between physical devices and digital components (Capestro & Kinkel, 2020). Interestingly, artificial intelligence (AI) is only mentioned in two of the selected texts (Abele et *al., 2*019; Wilkesmann & Wilkesmann, 2018).

Implications for KM. Industry 4.0 is understood as a "subclass of digital transformation" (Shamim *et al.*, 2017) with a focus on factories (Scheer, 2020). The attention to specific technologies (CPS, IoT) over others (AI) is likely to have significant consequences for humans' work with technology, such as a greater emphasis on knowledge about the shopfloor, for example (technical) expertise about production systems (Abele *et al.*, 2019). In addition, the flexibility and agility introduced by new technologies like CPS and IoT expose production workers to a constant and rapid rotation of tasks (Abele *et al.*, 2019; Flores *et al.*, 2020; Franken & Franken, 2018; Kohler & Weisz, 2016; Wilkesmann & Wilkesmann, 2018) and the need to multitask (Shamim *et al.*, 2017). Consequently, scholars highlight an increased responsibility and autonomy of employees (Agostini & Filippini, 2019; Erol *et al.*, 2016; Franken & Franken, 2018) which is also delegated to lower hierarchical levels (Kopp *et al.*, 2019; Shamim *et al.*, 2017; Trompisch, 2017; Wilkesmann & Wilkesmann, 2018). Hence employees acquire new knowledge more autonomously (Harteis & Fischer, 2017; Kopp *et al.*, 2019), but also in shorter time periods (Ilvonen, Thalmann, Manhart, & Sillaber, 2019) and more rapidly (Abele *et al.*, 2019; Roblek *et al.*, 2016). Managers, in turn, are to promote practices such as continuous mentoring, consulting, delegation or role modeling (Franken & Franken, 2018; Shamim *et al.*, 2017).

Facet 3: Interconnected networks

The third facet adds another layer of complexity. Supported by new technologies, it is argued that Industry 4.0 leads to a "ubiquitous connectivity and tracking" (Whysall, Owtram, & Brittain, 2019) of an array of "entities involved in the value creation" (Wilkesmann & Wilkesmann, 2018, p. 240) (machines, humans such as workers, suppliers and clients, technology, organizations, knowledge etc.) (Franken & Franken, 2018; Whysall *et al.*, 2019)—also referred to as "value (creation) networks" (Kagermann *et al.*, 2013; Schneider, 2018) or "intelligent networks along the entire value chain" (Agostini & Filippini, 2019). As such, Industry 4.0 is discussed as a "new type of networked value chain" (Capestro & Kinkel, 2020) and a "factory with networked equipment" (Abele *et al.*, 2019).

Implications for KM. These interconnections lead to new dynamics of human-machine interaction (Johansson, Abrahamsson, Bergvall Kåreborn, Fältholm, Grane, & Wykowska, 2017; Kagermann *et al.*, 2013; Kopp *et al.*, 2019; Pfeiffer, 2017), allowing employees to learn how to use these new technological devices. The question is whether humans can and must stay in control by the means of their "practical knowledge" and their "heterogeneous levels of experience" (Kopp *et al.*, 2019) or if technology might bind and therefore inhibit human interaction (Ansari, 2019; Schwab, 2016). Supporting the perspective of human control over technology, KM scholars recognize the importance of integrating explicit and tacit human knowledge in the networked environment (Johansson *et al.*, 2017). Expert knowledge is needed to interpret, apply, and make sense of the massive amounts of data (Thornley *et al.*, 2016) as well as to coordinate the workplace consisting of physical and digital machines (Karacay, 2018), also called "digital thinking" (Capestro & Kinkel, 2020; Roblek *et al.*, 2016). Further, the interconnected organization offers a new training environment where technologies like mixed-reality devices provide instant feedback on human actions (Schneider, 2018). From a techno-critical standpoint, scholars question however the superior status of employees over machines as well as the role of humans as sole knowledge actors (Ansari, 2019; Roblek *et al.*, 2016) when humans are put on the same level as technological building blocks like machines, devices and systems, thus merging into a "blended workforce" (Pfeiffer, 2017). Using technologies such as smart glasses and tablets as intermediaries of social interactions (Schwab, 2016) might lead to a loss of real human exchange (Foresti & Varvakis, 2018; Kohler & Weisz, 2016).

Facet 4: Control by smart and autonomous devices

The fourth and last facet demonstrates the fascination of the idea that 4.0-related technologies can act "autonomously." Such technologies (but also devices, factories, etc.) are referred to as "smart" (Ansari, 2019; Blanchet, 2016; Calış Duman & Akdemir, 2021; Capestro & Kinkel, 2020; Flores et *al.,* 2020; Kagermann et *al.,* 2013; Roblek et *al.,* 2016; Schwab, 2016). A device is defined as "smart" if it carries properties like quality and required production steps on a chip (Scheer, 2020) and can take decisions based on data (Sopadang et *al.,* 2020) and in real time (Wilkesmann & Wilkesmann, 2018). Hence, this facet refers to technology which is self-organized (Scheer, 2020) and thus allegedly "intelligent" (Agostini & Filippini, 2019; Kohler & Weisz, 2016). Due to its novelty and disruptive character, the idea of a self-controlling factory is even described as "the most important digital driver" (Scheer, 2020, p. 37) of Industry 4.0.

Implications for KM. The presence of decision-making algorithms (Franken & Franken, 2018) makes human experience merely an "interfering element" (Pfeiffer & Suphan, 2018) impacting humans' future decision-making abilities. Due to the premise that employees need decision support in the new highly complex work environment (Flores *et al.*, 2020; Ilvonen *et al.*, 2018), human workers move from "doing" to "having it done" (Blanchet, 2016), free of human fallibility (Johansson *et al.*, 2017). Consequently, human knowledge and especially long-term expertise risk being limited to situations of trouble-shooting, resulting in the famous "ironies of automation", a phenomenon frequently associated with the context of Industry 4.0. Other authors are more optimistic in arguing that human experience in the form of "experience-based knowledge work" is still needed (Pfeiffer, 2016), for example for the maintenance of the IoT or the monitoring of AI software (Sergi, Popkova, Bogoviz, & Litvinova, 2019) or for managing unpredictable events (Pfeiffer, 2016).

Discussion

Our analysis led to three main contributions. The first contribution is to the field of KM in general. Inspired by the four facets of Industry 4.0 which have emerged from the narrative literature review, we laid out several implications for KM. In a next step and based on these findings, we formulate and discuss implications of intergenerational knowledge transmission for each facet. We highlight generational considerations in organizational contexts increasingly dominated by technology and point towards emerging intergenerational knowledge transmission practices in the Industry 4.0 context. Figure 1 presents the linkages between the four facets, the implications for KM and the new practices of intergenerational knowledge transmission. Insights on organizational examples for each facet are presented in Appendix B.

FIGURE 1

Facets of Industry 4.0 and implications for intergenerational knowledge transmission

Implications and considerations for intergenerational knowledge transmission

Continuous and personalized intergenerational knowledge co-construction (Facet 1)

The implications of Facet 1 for intergenerational knowledge transmission can be summarized as intergenerational collaboration for knowledge co-construction, multi-generational teams and personalized practices. The analysis of the human-centered literature on Industry 4.0 suggests that the concept has still to materialize and remains until then a paradigmatic vision. If this vision is to be realized, though, organizations need to engage in a deep preparation process. For KM, this means that the adaptation requirements for human workers are high and complex. Intergenerational collaboration is likely to be an organizational priority for fostering knowledge co-construction in the preparation phase. Indeed, matching the discussion in literature on Industry 4.0, the literature on intergenerational knowledge transmission progressively highlights the importance of new learning forms to prepare employees for the future work environment. While scholars have already highlighted the importance of age-diverse teams due to the generations' complementary knowledge (Kearney, Gebert, & Voelpel, 2009), several more recent studies focused on intergenerational learning in teams (Gerpott *et al.*, 2017; Gerpott, Lehmann-Willenbrock, Wenzel, & Voelpel, 2021). Hence, implementing the visionary paradigm of Industry 4.0 leads to rethinking the classical view of the inter-generational dyad. Even though the number of studies on multigenerational teams and collective learning experience is increasing, the literature on intergenerational knowledge transmission currently lacks research which considers the interaction of these teams with technology. It will notably be crucial to combine work on multigenerational teams (Gerpott *et al.*, 2021) with insights from studies in tech-intensive environments (Anthony, 2019; Beane, 2019). Expertise and the capacity of problem solving are also discussed in the literature on intergenerational knowledge transmission. Seniors who have accumulated knowledge over the years and developed experience are described as "deep smarts" (Leonard & Swap, 2005). Their knowledge is called *phronesis*—a form of tacit knowledge described as practical wisdom (Nonaka & Toyama, 2007)—and might be of central importance when paving the way for Industry 4.0. Further, a shift away from content-based intergenerational knowledge transmission (e.g., expert interviews) towards personalized practices such as mentoring or counseling could accompany the paradigmatic change discussed in the literature on Industry 4.0. Despite the potential benefits of innovative KM techniques like communities of practices or world cafés, organizations might have to deal with skepticism among managers—even the younger ones—regarding novel and more personalized practices (Maier & Reimer, 2018).

Generational mutuality and continuity (Facet 2)

Facet 2 leads to generational mutuality, bi- and multi-directional knowledge flows between generations and continuous knowledge acquisition and collective unlearning. Our findings indicate that Industry 4.0 is mostly concerned with profound changes in the manufacturing industries where it creates—from a KM perspective—an autonomous and high-speed work environment. High expectations and requirements in terms of knowledge acquisition are imposed on employees of all hierarchical levels. From the perspective of intergenerational knowledge transmission, the continuous integration of new knowledge matches the ongoing scholarly discussion on bi- and multidirectional knowledge flows between generations. Several studies point to the need of knowledge

transmission from younger to older workers—for example, through reverse mentoring (Marcinkus Murphy, 2012) or intergenerational learning (Gerpott *et al.*, 2017; Knight, Skouteris, Hooley, & Townsend, 2014). In this sense, Simola (2016) introduced the concept of mutuality without hierarchical relations between generations but the interchange between novices and more experienced workers (p. 348). The digital context makes intergenerational collaboration in the context of new technologies and situations crucial (Šestáková, 2019), leading to a "generational metamorphosis" which involves "swinging in apprenticeship where generations either act as teachers or learners" (Rondi, Überbacher, Von Schlenk Barnsdorf, & Hülsbeck, 2021, p. 1). Intergenerational knowledge transmission then acts as an important base for innovation and change (Rondi *et al.*, 2021; Woodfield & Husted, 2017), rather than preserving the knowledge base from the past (Prügl & Spitzley, 2021) or strengthening routine (Rondi *et al.*, 2021). Further, the traditional conceptualization of mentoring based on a single dyadic relationship has become obsolete and replaced by a career related developmental network perspective (Higgins & Kram, 2001), often preferred by younger workers (Andriani, Christiandy, Wiratmadja, & Sunaryo, 2022).

The idea of younger workers transferring their knowledge to their senior colleagues also becomes essential. Despite the presence of research on practices such as reverse transmission, we notice a lack of critical research exploring the risks which can emerge alongside a strong tech-fascination and therefore a disbalanced focus on younger workers and their knowledge. Further, rather than storing knowledge in IT systems or archives, organizational knowledge bases need to be continuously renewed. However, the importance of discarding obsolete knowledge and unlearning—largely discussed in the KM literature (e.g., Becker, 2018)—is not explicitly mentioned by scholars studying intergenerational knowledge transmission. Unlearning may be especially challenging for employees with rich tacit knowledge, specific expertise, and experience, and can be inhibited by the organizational memory built on old knowledge and routines (Becker, 2018). From a generational perspective, one major assumption is that seniors are disproportionally affected by the challenges of unlearning. Continuous experimentation and collective unlearning which lead to joint new understandings can help to overcome such challenges (Fiol & O'Connor, 2017).

Technology as facilitator or risk factor for intergenerational knowledge transmission (Facet 3)

When considering Facet 3, we see new forms of intergenerational knowledge transmission and learning with technological intermediaries emerge, where technology can act as leverage or inhibitor. The results of the narrative review point to a trend in which new technologies are connected to other objects and subjects along the value chain. Close human-machine interaction could be the essential consequence for KM, for example by using virtual reality like smart glasses. A scarce number of empirical studies explore new forms of intergenerational knowledge transmission by means of technological intermediaries. Notably, Schlegel and colleagues (2021) document an exploratory intergenerational learning experiment using virtual reality and point out that the experience is mostly perceived as positive rather than as cognitively overwhelming, thus enhancing and leveraging knowledge transmission to novices. Despite this empirical evidence, the risks of human-machine collaboration for intergenerational knowledge transmission cannot be ignored. Anthony (2021) found that both junior and senior workers had a limited understanding of algorithms they were meant to use. One reason for this "black boxing" was that the algorithm's use led to a partitioning of work tasks, with juniors only executing the algorithm (without any critical analysis) and seniors merely interpreting the results (without any technological understanding). By intruding elementary work practices, technologies can change organizational structures of work, leading to the emergence of practices like clandestine teaching (i.e., giving advice without affronting the existing status system) and role reversal (Barley, 1986). Indeed, Beane (2019) found a new subversive and informal form of "shadow learning" which is experienced by younger surgeons using robotic technology. The practice of shadow learning limits them in their capacity to participate in their mentor's work and to engage in traditional knowledge transmission through direct observation and targeted learning practices. Seen from a communities-of-practice perspective, the use of new technologies inhibits legitimized peripheral participation, thus questioning the benefits of interconnected networks and value chains for the transmission of knowledge from one generation to another.

Considerations about sharing and losing (senior) tacit knowledge (Facet 4)

From a KM viewpoint, our analysis shows that industry applications for Industry 4.0 adhere to the ideal that "smart" and "intelligent" devices become the principal decision-makers on the shop floor. In a situation where humans are merely responsible for troubleshooting, the challenge of preserving tacit knowledge, as it has been discussed in various KM studies, is likely to experience a revival. When managerial practices are very technology-based, for example by capturing knowledge in IT systems, the danger of losing such valuable knowledge is high (McNichols, 2010). This risk is exacerbated when using algorithms or related technologies (Dragicevic, Ullrich, Tsui, & Gronau, 2020; Faraj, Pachidi, & Sayegh, 2018; Holford, 2020). A key consideration for intergenerational knowledge transmission in this regard is the role of seniors' tacit knowledge. Taking the power of smart technologies seriously, the sensory experience of older workers might decrease in organizational importance. It must however be noted that tacit knowledge of seniors is highly important for organizations, especially in technology-intensive industries such as aerospace (Ebrahimi *et al.*, 2008; McNichols, 2010). To compensate for potential losses, scholars emphasize the need for managerial practices such as mentoring or shadowing where the transmission of tacit knowledge is facilitated through trust relationships and observation (Kuyken *et al.*, 2018). Having said this, organizations—but also KM scholars—will have to deal with a highly ambiguous work environment which is, on the one hand, hostile to (seniors') tacit knowledge, but conscious about the value of routine-based expertise on the other (Pfeiffer & Suphan, 2018).

A human-centered definition of Industry 4.0

In addition to our contribution to the fields of intergenerational knowledge transmission and KM, our paper contributes to the literature on Industry 4.0 with the formulation of a new, human-focused definition of the term. As highlighted earlier, a greater academic spotlight on the sociological dynamics in modern organizations which are emerging due to accelerated technological change is required. While a human-centered understanding of Industry 4.0 is partially available, a refined and focused definition can guide KM research as it explores its role in the 21st century. Based on previous reflections and following the call of Piccarozzi and colleagues (2018) that a distinct conception of Industry 4.0 in management studies is needed, we propose the following human-centered

definition of Industry 4.0: *Industry 4.0 represents the prospect of an industrial workplace which is characterized by the increasingly combined use of different emerging and existing technologies, unsettling organizationally well-established conventions and practices regarding human knowledge and generation-specific expertise.*

Avenues for future research

Our contributions to the literature on KM and intergenerational knowledge transmission also lead to identifying different research gaps and avenues for future research in the era of Industry 4.0. Our analysis revealed that some key aspects of the two literature streams relevant in the context of Industry 4.0 are not studied at all or remain at least underexplored. Table 1 provides a summary of selected questions which may inspire management scholars eager to push forward academic work at the intersection of KM, intergenerational knowledge transmission and Industry 4.0.

TABLE 1

Questions for future research on intergenerational knowledge transmission in the context of Industry 4.0

Facet	Research questions
Facet 1: Visionary paradigm	- How can generations learn together to acquire new theoretical knowledge? - How does experience (and therefore knowledge) develop within a group? - Which individualized practices of intergenerational knowledge transmission are relevant in the context of Industry 4.0 and how can management support them?
Facet 2: Digitalization of the industry	- What are the effects on seniors and their knowledge sharing behavior when organizations strongly encourage knowledge transmission from younger to senior workers? - What are downsides of the decomposition of the classical intergenerational dyad? - Which dysfunctional intergenerational relationships and new power dynamics can occur in the era of Industry 4.0? - How do generations deal with obsolete knowledge when building collective expertise in the context of Industry 4.0? - Which situations of collective (un)learning are crucial for intergenerational knowledge transmission?
Facet 3: Interconnected networks	- What are new work situations, role attributions, practices, possibilities, and challenges for intergenerational knowledge transmission when interacting with machinery? - Which patterns of human-machine interaction (don't) foster intergenerational knowledge transmission?
Facet 4: Control by smart and autonomous devices	- How can seniors' tacit knowledge be shared in the context of Industry 4.0? - Which challenges arise, and how can the risks of losing valuable tacit knowledge be reduced or eliminated?

Conclusion

Based on the findings and contributions of our analysis, the implications of Industry 4.0 on intergenerational knowledge transmission can be summarized as follows: intergenerational knowledge transmission has shifted in its *orientation* (from one-directional to co-constructive), in its *form* (from dyad-based practices to multi-relational knowledge transmission), as well as in its *degree of standardization* (from organizational standards to the individualization of practices) and has led to several *risks and considerations*, especially when it comes to sharing tacit knowledge. Despite the possible limitations of this study (e.g., scope of included papers), our research shows the importance and promising character of further research on intergenerational knowledge transmission. We invite practitioners to move away from the classical paradigm of intergenerational knowledge transmission, and to conceive new—co-constructive, collective, and individualized—practices instead.

References

The references tagged with an asterisk (*) are the results of the narrative literature review.

*Abele, E., Metternich, J., & Tisch, M. (2019). *Learning Factories—Concepts, Guidelines, Best-Practice Examples*. Springer International Publishing.

*Agostini, L., & Filippini, R. (2019). Organizational and managerial challenges in the path toward Industry 4.0. *European Journal of Innovation Management, 22*(3), 406–421. https://doi.org/10.1108/EJIM-02-2018-0030

Andriani, M., Christiandy, A., Wiratmadja, I., & Sunaryo, I. (2022). Knowledge Management Effectiveness Model in facilitating Generation Differences. *Knowledge Management Research & Practice*, 1–13. https://doi.org/10.1080/14778238.2022.2129494

*Ansari, F. (2019). Knowledge Management 4.0: Theoretical and Practical Considerations in Cyber Physical Production Systems. *IFAC PapersOnLine, 52*(13), 1597–1602. https://doi.org/10.1016/j.ifacol.2019.11.428

Anthony, C. (2021). When Knowledge Work and Analytical Technologies Collide: The Practices and Consequences of Black Boxing Algorithmic Technologies. *Administrative Science Quarterly*, *66*(4), 1173–1212. https://doi.org/10.1177/00018392211016755

Autor, D. H. (2015). Why Are There Still So Many Jobs? The History and Future of Workplace Automation. *Journal of Economic Perspectives*, *29*(3), 3–30. http: //www.jstor.org/stable/43550118

Barley, S. R. (1986). Technology as an Occasion for Structuring: Evidence from Observations of CT Scanners and the Social Order of Radiology Departments. *Administrative Science Quarterly*, *31*(1), 78–108. https://doi.org/10.2307/2392767

Baskerville, R., & Dulipovici, A. (2006). The theoretical foundations of knowledge management. *Knowledge Management Research & Practice*, *4*(2), 83–105. https://doi.org/10.1057/palgrave.kmrp.8500090

Baumeister, R. F., & Leary, M. R. (1997). Writing Narrative Literature Reviews. *Review of General Psychology*, *1*(3), 311–320. https://doi.org/10.1037/1089-2680.1.3.311

Beane, M. (2019). Shadow learning: building robotic surgical skill when approved means fail. *Administrative Science Quarterly*, *64*(1), 87–123. https://doi.org/10.1177/0001839217751692

Beazley, H., Boenisch, J., & Hardan, D. (2002). *Continuity management: preserving corporate knowledge and productivity when employees leave*. Wiley.

Becker, K. (2018). Organizational Unlearning: Time to Expand Our Horizons? *Learning Organization, 25*(3), 180–189. https://doi.org/10.1108/TLO-10-2017-0095

* Blanchet, M. (2016). Industrie 4.0. Nouvelle donne industrielle, nouveau modèle économique. *Outre-Terre*, 46(1), 62-85. https://doi.org/10.3917/oute1.046.0062

Bootz, J.-P., Michel, S., Pallud, J., & Monti, R. (2022). Possible changes of Industry 4.0 in 2030 in the face of uberization: Results of a participatory and systemic foresight study. *Technological Forecasting & Social Change*, *184*, 1–21. https://doi.org/10.1016/j.techfore.2022.121962

Bosse, C. K., Hellge, V., & Schröder, D. (2019). Partizipation als Schlüssel zum Erfolg. *Mittelstand-Digital Magazin*(11), 5-11.

Brown, J. S., & Duguid, P. (1991). Organizational learning and communities-of-practice: Toward a unified view of working, learning, and innovation. *Organization Science*, *2*(1), 40–57. https://doi.org/10.1287/orsc.2.1.40

*Calışş Duman, M., & Akdemir, B. (2021). A study to determine the effects of industry 4.0 technology components on organizational performance. *Technological Forecasting & Social Change*, *167*, 1–14. https://doi.org/10.1016/j.techfore.2021.120615

*Capestro, M., & Kinkel, S. (2020). Industry 4.0 and Knowledge Management: A Review of Empirical Studies. In M. Bettiol, E. Di Maria, & S. Micelli (Eds.), *Knowledge Management and Industry 4.0. New Paradigms for Value Creation* (Vol. 9, pp. 19–52). Springer Nature Switzerland.

Carlile, P. R. (2002). A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development. *Organization Science*, *13*(4), 442–455. https://doi.org/10.1287/orsc.13.4.442.2953

Cronin, P., Ryan, F., & Coughlan, M. (2008). Undertaking a literature review: A step-by-step approach. *British Journal of Nursing*, *17*(1), 38–43. https://doi.org/10.12968/bjon.2008.17.1.28059

De Long, D. W., & Davenport, T. (2003). Better practices for retaining organizational knowledge: Lessons from the leading edge. *Employment Relations Today, 30*(3), 51–63. https://doi.org/10.1002/ert.10098

Dragicevic, N., Ullrich, A., Tsui, E., & Gronau, N. (2020). A conceptual model of knowledge dynamics in the industry 4.0 smart grid scenario. *Knowledge Management Research & Practice, 18*(2), 199–213. https://doi.org/10.1080/14778238.2019.1633893

Easterby-Smith, M., & Lyles, M. A. (2011). *Handbook of Organizational Learning and Knowledge Management* (Second ed.). Wiley.

Ebrahimi, M., Saives, A. L., & Holford, W. D. (2008). Qualified ageing workers in the knowledge management process of high-tech businesses. *Journal of Knowledge Management, 12*(2), 124–140. https://doi.org/10.1108/13673270810859569

Ermine, J. L. (2010). Une démarche pour le transfert intergénérationnel des savoirs. *Téléscope*, *16*(1), 83-107.

*Erol, S., Jäger, A., Hold, P., Ott, K., & Sihn, W. (2016). Tangible Industry 4.0: A Scenario-Based Approach to Learning for the Future of Production. *Procedia CIRP, 54*, 13–18. https://doi.org/10.1016/j.procir.2016.03.162

Faraj, S., Pachidi, S., & Sayegh, K. (2018). Working and organizing in the age of the learning algorithm. *Information and Organization, 28*(1), 62–70. https://doi.org/10.1016/j.infoandorg.2018.02.005

Ferrari, R. (2015). Writing narrative style literature reviews. *Medical Writing*, *24*(4), 230–235. https://doi.org/10.1179/2047480615Z.000000000329

Fiol, M., & O'Connor, E. (2017). Unlearning Established Organizational Routines—Part I. *Learning Organization, 24*(1), 13–29. https://doi.org/10.1108/TLO-09-2016-0056

*Flores, E., Xu, X., & Lu, Y. (2020). Human Capital 4.0: a workforce competence typology for Industry 4.0. *Journal of Manufacturing Technology Management, 31*(4), 687–703. https://doi.org/10.1108/JMTM-08-2019-0309

Foray, D. (2009). *L'économie de la connaissance*: La Découverte.

*Foresti, F., & Varvakis, G. (2018). Ubiquity and Industry 4.0. In K. North, R. Maier, & O. Haas (Eds.), *Knowledge Management in Digital Change: New Findings and Practical Cases* (pp. 343–358). Springer International Publishing.

Frank, H., & Hatak, I. (2014). Doing a research literature review. In A. Fayolle & M. Wright (Eds.), *How to get published in the best entrepreneurship journals: a guide to steer your academic career* (pp. 94–117). Edward Elgar Publishing.

*Franken, R., & Franken, S. (2018). Wandel von Mangementfunktionen im Kontext der Digitalisierung. In H. Hirsch-Kreinsen, P. Ittermann, & J. Niehaus (Eds.), *Digitalisierung industrieller Arbeit. Die Vision Industrie 4.0 und ihre sozialen Herausforderungen* (2nd ed., pp. 99-120). Nomos.

Frey, C. B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation? *Technological Forecasting and Social Change*, *114*, 254–280. https://doi.org/10.1016/j.techfore.2016.08.019

Gerpott, F. H., & Fasbender, U. (2020). Intergenerational learning in age-diverse meetings: A social comparison perspective. In A. L. Meinecke, J. A. Allen, & N. Lehmann-Willenbrock (Eds.), *Managing Meetings in Organizations* (Vol. 20, pp. 185–206). Emerald Publishing Limited.

Gerpott, F. H., Lehmann-Willenbrock, N., & Voelpel, S. C. (2017). A Phase Model of Intergenerational Learning in Organizations. *Academy of Management Learning & Education, 16*(2), 193–216. https://doi.org/10.5465/amle.2015.0185

Gerpott, F. H., Lehmann-Willenbrock, N., Wenzel, R., & Voelpel, S. C. (2021). Age diversity and learning outcomes in organizational training groups: the role of knowledge sharing and psychological safety. *The International Journal of Human Resource Management*, *32*(18), 3777–3804. https://doi.org/10.1080/09585192.2019.1640763

Green, B. N., Johnson, C. D., & Adams, A. (2006). Writing Narrative Literature Reviews for Peer-Reviewed Journals: Secrets of the Trade. *Journal of Chiropractic Medicine*, *5*(3), 101–117. https://doi.org/10.1016/S0899-3467(07)60142-6

*Harteis, C., & Fischer, C. (2017). Wissensmanagement unter Bedingungen von Arbeit 4.0. In G. W. Maier, G. Engels, & E. Steffen (Eds.), *Handbuch Gestaltung digitaler und vernetzter Arbeitswelten* (p. 1–18). Springer Berlin Heidelberg.

Harvey, J.-F. (2012). Managing organizational memory with intergenerational knowledge transfer. *Journal of Knowledge Management, 16*(3), 400–417. https://doi.org/10.1108/13673271211238733

Higgins, M. C., & Kram, K. E. (2001). Reconceptualizing mentoring at work: A developmental network perspective. *Academy of Management Review, 26*(2), 264–288. https://doi.org/10.2307/259122

Hirsch-Kreinsen, H., Ittermann, P., & Niehaus, J. (Eds.). (2018). *Digitalisierung industrieller Arbeit. Die Vision Industrie 4.0 und ihre sozialen Herausforderungen* (2nd ed.). Nomos.

Holford, D. W. (2020). *Managing Knowledge in Organizations. A Critical Pragmatic Perspective*. Palgrave Macmillan.

IDW. (2021). *Projekt KüSTE mit Künstlicher Intelligenz zur Erfahrungssicherung beim Generationswechsel in Unternehmen*. https://nachrichten.idw-online.de/2021/07/02/projekt-kueste-mit-kuenstlicher-intelligenz-zur-erfahrungssicherung-beim-generationswechsel-in-unternehmen

IBM. (2019). *EcoPlant: Cutting energy waste by up to 50 percent*. https://www.ibm.com/case-studies/ecoplant

*Ilvonen, I., Thalmann, S., Manhart, M., & Sillaber, C. (2018). Reconciling digital transformation and knowledge protection: a research agenda. *Knowledge management research & practice, 16*(2), 235–244. https://doi.org/10.1080/14778238.2018.1445427

*Johansson, J., Abrahamsson, L., Bergvall Kåreborn, B., Fältholm, Y., Grane, C., & Wykowska, A. (2017). Work and Organization in a Digital Industrial Context. *Management Revue*, *28*(3), 281–297. http: //www.jstor.org/stable/26381577

Joshi, A., Dencker, J. C., Franz, G., & Martocchio, J. J. (2010). Unpacking generational identities in organizations. *Academy of Management Review, 35*(3), 392–414. http: //www.jstor.org/stable/25682421

Julien, N., & Martin, É. (2021). *L'usine du futur: Stratégies et déploiement. Industrie 4.0, de l'IoT aux jumeaux numériques* (2nd ed.). Dunod.

*Kagermann, H., Wahlster, W., & Helbig, J. (2013). *Recommendations for implementing the strategic initiative INDUSTRIE 4.0. Final report of the Industrie 4.0 Working Group*. Retrieved from https://en.acatech.de/publication/recommendations-for-implementing-the-strategic-initiative-industrie-4-0-final-report-of-the-industrie-4-0-working-group/

*Karacay, G. (2018). Talent Development for Industry 4.0. In A. Ustundag & E. Cevikcan (Eds.), *Industry 4.0: Managing The Digital Transformation* (p. 123–136). Springer.

Kearney, E., Gebert, D., & Voelpel, S. C. (2009). When and how diversity benefits teams: The importance of team members' need for cognition. *The Academy of Management Journal*, *52*(3), 581–598. http: //www.jstor.org/stable/40390305

Knight, T., Skouteris, H., Hooley, M., & Townsend, M. (2014). The Act of Giving: A Systematic Review of Nonfamilial Intergenerational Interaction. *Journal of Intergenerational Relationships, 12*(3), 257–278. https://doi.org/10.1080/15350770.2014.929913

Kogut, B., & Zander, U. (1992). Knowledge of the firm, combinative capabilities, and the replication of technology. *Organization Science*, *3*(3), 383–397. https://doi.org/10.1287/orsc.3.3.383

*Kohler, D., & Weisz, J.-D. (2016). *Industrie 4.0. Les défis de la transformation numérique du modèle industriel allemand*. La documentation française.

*Kohler, D., & Weisz, J. (2017). Industrie 4.0, une révolution sociétale? *Allemagne d'aujourd'hui*, *222*(4), 44-58. https://doi.org/10.3917/all.222.0044

*Kopp, R., Dhondt, S., Hirsch-Kreinsen, H., Kohlgrüber, M., & Preenen, P. (2019). Sociotechnical perspectives on digitalisation and Industry 4.0. *International Journal of Technology Transfer and Commercialisation, 16*, 290. https://doi.org/10.1504/IJTTC.2019.099896

Kuyken, K., Ebrahimi, M., & Saives, A.-L. (2018). Towards a taxonomy of intergenerational knowledge transfer practices: insights from an international comparison (Germany—Quebec). *The Learning Organization, 25*(2), 81–91. https://doi.org/10.1108/TLO-02-2017-0023

Lave, J., & Wenger, É. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Leonard, D., & Swap, W. C. (2005). *Deep Smarts: How to Cultivate and Transfer Enduring Business Wisdom*. Harvard Business Press.

Levy, M. (2011). Knowledge retention: minimizing organizational business loss. *Journal of Knowledge Management, 15*(4), 582–600. https://doi.org/10.1108/13673271111151974

Lindner, D., Ludwig, T., & Amberg, M. (2018). Arbeit 4.0 – Konzepte für eine neue Arbeitsgestaltung in KMU. *HMD Praxis der Wirtschaftsinformatik, 55*(5), 1065-1085. https://doi.org/10.1365/s40702-018-0425-7

*Maier, E., & Reimer, U. (2018). Digital Change—New Opportunities and Challenges for Tapping Experience and Lessons Learned for Organisational Value Creation. In K. North, R. Maier, & O. Haas (Eds.), *Knowledge Management in Digital Change* (pp. 83–96). Springer.

Marcinkus Murphy, W. (2012). Reverse mentoring at work: Fostering cross-generational learning and developing millennial leaders. *Human Resource Management, 51*(4), 549–573. https://doi.org/10.1002/hrm.21489

McNichols, D. (2010). Optimal knowledge transfer methods: a Generation X perspective. *Journal of Knowledge Management*, *14*(1), 24–37. https://doi.org/10.1108/13673271011015543

*Meindl, B., Ayala, N. F., Mendonça, J., & Frank, A. G. (2021). The four smarts of Industry 4.0: Evolution of ten years of research and future perspectives. *Technological Forecasting & Social Change*, *168*, 1–13. https://doi.org/10.1016/j.techfore.2021.120784

Mertens, P., Barbian, D., & Baier, S. (2017). *Digitalisierung und Industrie 4.0 – eine Relativierung*. Springer Vieweg.

Mitchell, H. (2007). Technology and Knowledge Management: Is Technology Just an Enabler or Does it also Add Value? In M. E. Jennex (Ed.), *Knowledge Management: Concepts, Methodologies, Tools, and Applications* (pp. 41–47). Idea Group Publishing.

Nonaka, I., & Takeuchi, H. (1995). *The Knowledge-Creating Company. How Japanese Companies Create the Dynamics of Innovation*. Oxford University Press.

Nonaka, I., & Toyama, R. (2007). Strategic management as distributed practical wisdom (phronesis). *Industrial and Corporate Change, 16*(3), 371–394. https://doi.org/10.1093/icc/dtm014

North, M. S., & Fiske, S. T. (2015). Intergenerational resource tensions in the workplace and beyond: Individual, interpersonal, institutional, international. *Research in Organizational Behavior*, *35*, 159–179. https://doi.org/10.1016/j.riob.2015.10.003

Pacaux-Lemoine, M.-P., Trentesaux, D., Zambrano, R. G., & Millot, P. (2017). Designing intelligent manufacturing systems through Human-Machine Cooperation principles: A human-centered approach. *Computers & Industrial Engineering*, *111*, 581–595. https://doi.org/10.1016/j.cie.2017.05.014

Paré, G., Trudel, M. C., Jaana, M., & Kitsiou, S. (2015). Synthesizing information systems knowledge: A typology of literature reviews. *Information & Management, 52*(2), 183–199. https://doi.org/10.1016/j.im.2014.08.008

*Pfeiffer, S. (2016). Robots, Industry 4.0 and Humans, or Why Assembly Work Is More than Routine Work. *Societies, 6*(2), 1–26. https://doi.org/10.3390/soc6020016

*Pfeiffer, S. (2017). The Vision of "Industrie 4.0" in the Making—a Case of Future Told, Tamed, and Traded. *NanoEthics, 11*(1), 107–121. https://doi.org/10.1007/s11569-016-0280-3

*Pfeiffer, S., & Suphan, A. (2018). Industrie 4.0 und Erfahrung – das unterschätzte Innovations- und Gestaltungspotenzial der Beschäftigten im Maschinen- und Automobilbau. In H. Hirsch-Kreinsen, P. Ittermann, & J. Niehaus (Eds.), *Digitalisierung industrieller Arbeit. Die Vision Industrie 4.0 und ihre sozialen Herausforderungen* (2nd ed., pp. 275-302). Nomos.

Piccarozzi, M., Aquilani, B., & Gatti, C. (2018). Industry 4.0 in Management Studies: A Systematic Literature Review. *Sustainability*, *10*, 1–24. https://doi.org/10.3390/su10103821

Polanyi, M. (1967). *The tacit dimension*. Doubleday.

Porsche. (2020). *Augmented Reality Usage Triples in Porsche Workshops Amid COVID-19*. https://newsroom.porsche.com/en_US/technology/porsche-tech-live-look-augmented-reality-usage-covid-19-20702.html

Prahalad, C. K., & Hamel, G. (1990). *The core competence of corporation*. Harvard Business School Reprint.

*Prifti, L., Knigge, M., Kienegger, H., & Krcmar, H. (2017). *A Competency Model for "Industrie 4.0" Employees.* Paper presented at the 13th International Conference on Wirtschaftsinformatik, St. Gallen.

Prügl, R., & Spitzley, D. I. (2021). Responding to Digital Transformation by External Corporate Venturing: An Enterprising Family Identity and Communication Patterns Perspective. *Journal of Management Studies, 58*(1), 135–164. https://doi.org/10.1111/joms.12578

*Roblek, V., Meško, M., & Krapež, A. (2016). A Complex View of Industry 4.0. *SAGE Open, 6*(2), 1–11. https://doi.org/10.1177/2158244016653987

Roche. (2018). *Reverse mentoring: it's a two-way street*. https://www.roche.com/stories/reverse-mentoring

Rondi, E., Überbacher, R., Von Schlenk Barnsdorf, L., & Hülsbeck, M. (2021). Intergenerational Knowledge Transfer in Family Firms during Times of Digital Innovation. Academy of Management Proceedings. https://doi.org/10.5465/AMBPP.2021.13198abstract

*Schallock, B., Rybski, C., Jochem, R., & Kohl, H. (2018). Learning Factory for Industry 4.0 to provide future skills beyond technical training. *Procedia Manufacturing, 23*, 27–32. https://doi.org/10.1016/j.promfg.2018.03.156

*Scheer, A.-W. (2020). *Unternehmung 4.0* (Vol. 3rd edition). Springer Vieweg.

Schlegel, C., Geering, A., & Weber, U. (2021). Learning in virtual space: An intergenerational pilot project. *GMS Journal for Medical Education*, *38*(2), 1–14. https://doi.org/10.3205/zma001433

Schmidt, X., & Mühlfeld, K. (2017). What's so special about intergenerational knowledge transfer? Identifying challenges of intergenerational knowledge transfer. *Management Revue, 28*(4), 375–411. https://www.jstor.org/stable/26407256

* Schneider, P. (2018). Managerial challenges of industry 4.0: an empirically backed research agenda for a nascent field. *Review of Managerial Science*, 12(3), 803–848. https://doi.org/10.1007/s11846-018-0283-2 .

*Schwab, K. (2016). *The Fourth Industrial Revolution*. World Economic Forum.

*Sergi, B. S., Popkova, E. G., Bogoviz, A. V., & Litvinova, T. N. (2019). *Understanding Industry 4.0. AI, the Internet of Things, and the Future of Work*. Emerald Publishing Limited.

Šestáková, M. (2019). *The Human Factor in Industry 4.0 and Some of Its Intergenerational Implications*. Paper presented at the 14th International Workshop on Knowledge Management, Trenčín, Slovakia.

*Shamim, S., Cang, S., Yu, H., & Li, Y. (2017). Examining the Feasibilities of Industry 4.0 for the Hospitality Sector with the Lens of Management Practice. *Energies, 10*(4), 1–19. https://doi.org/10.3390/en10040499

Simola, S. (2016). Mentoring the morally courageous: a relational cultural perspective. *Career Development International, 21*(4), 340–354. https://doi.org/10.1108/CDI-01-2016-0010

*Sopadang, A., Chonsawat, N., & Ramingwong, S. (2020). Industry 4.0 for SMEs: Challenges, Opportunities and Requirements. In D. T. Matt, V. Modrák, & H. Zsifkovits (Eds.), *Industry 4.0 for SMEs: Challenges, Opportunities and Requirements* (pp. 279–302). Palgrave Macmillan.

Tempest, S. (2003). Intergenerational Learning A Reciprocal Knowledge Development Process that Challenges the Language of Learning. *Management learning, 34*(2), 181–200.

Thomas, J. C., Kellogg, W. A., & Erickson, T. (2001). The knowledge management puzzle: Human and social factors in knowledge management. *IBM Systems Journal, 40*(4), 863–884. https://doi.org/10.1147/sj.404.0863

*Thornley, C., Carcary, M., Connolly, N., O'Duffy, M., & Pierce, J. (2016). *Developing a Maturity Model for Knowledge Management (KM) in the Digital Age*. Paper presented at the 16th European Conference on Knowledge Management, Belfast, Ireland.

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, *14*(3), 207–222. https://doi.org/10.1111/1467-8551.00375

*Trompisch, P. (2017). Industrie 4.0 und die Zukunft der Arbeit. *Elektrotechnik und Informationstechnik, 134*(7), 370-373. https://doi.org/10.1007/s00502-017-0531-1

Tsoukas, H., & Vladimirou, E. (2001). What is organizational knowledge? *Journal of Management Studies, 38*(7), 973–993. https://doi.org/10.1111/1467-6486.00268

Vallourec. (2019). *Reverse mentors to support our digital transformation*. https://www.vallourec.com/en/components/news/news_corp/2019/20191004-reverse-mentors-support-digital-transfo

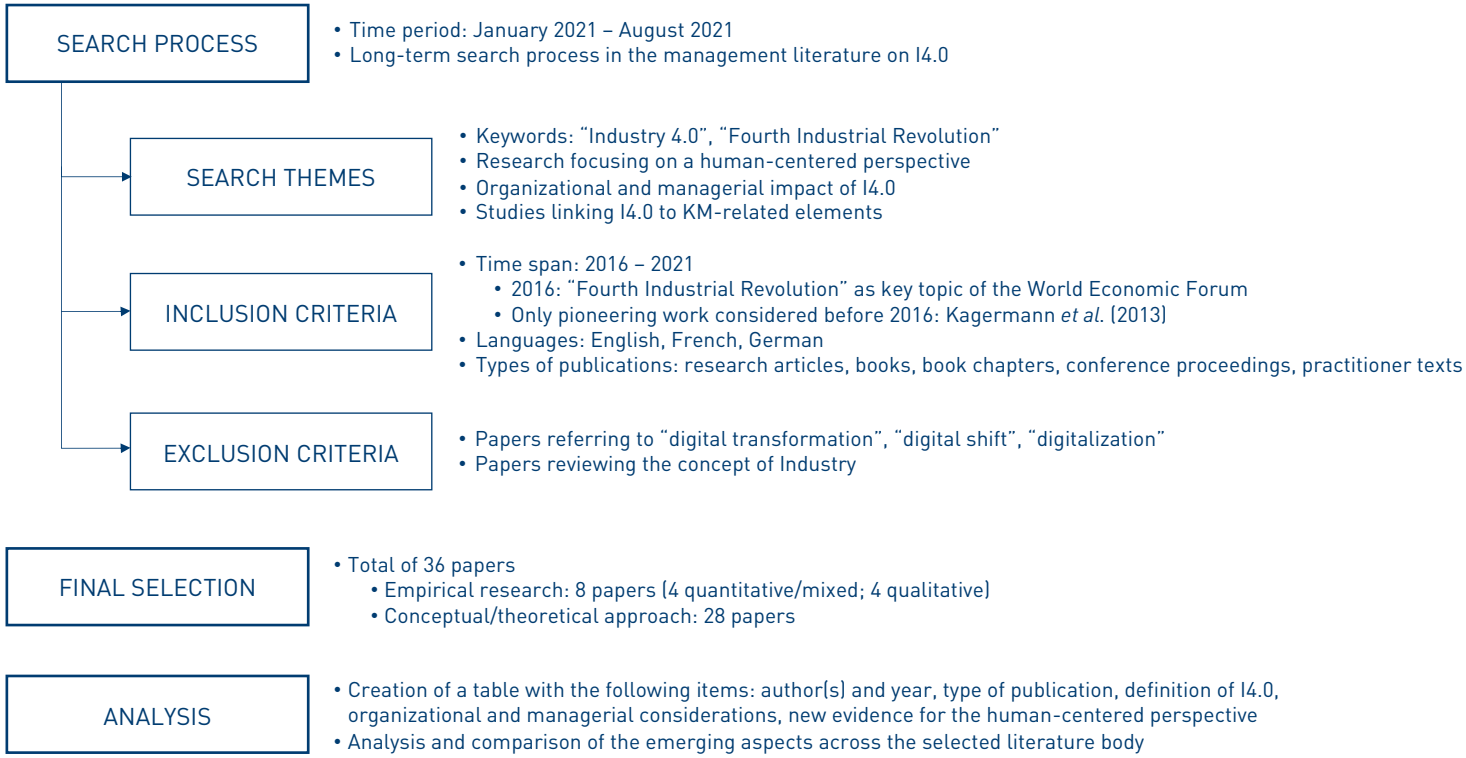
*Whysall, Z., Owtram, M., & Brittain, S. (2019). The new talent management challenges of Industry 4.0. *Journal of Management Development, 38*(2), 118–129. https://doi.org/10.1108/JMD-06-2018-0181

*Wilkesmann, M., & Wilkesmann, U. (2018). Industry 4.0—organizing routines or innovations? *VINE Journal of Information and Knowledge Management Systems, 48*(2), 238–254. https://doi.org/10.1108/VJIKMS-04-2017-0019

Woodfield, P., & Husted, K. (2017). Intergenerational knowledge sharing in family firms: Case-based evidence from the New Zealand wine industry. *Journal of Family Business Strategy, 8*(1), 57–69. https://doi.org/10.1016/j.jfbs.2017.01.001

APPENDIX A

Research process



APPENDIX B

Insights on the implications of Industry 4.0 for intergenerational knowledge transmission

INSIGHT 1. Employee empowerment as a first step towards the realization of Industry 4.0

In the German company Günter Effgen GmbH, a systems provider for grinding, the implication, understanding and acceptance of the employees has been a priority for the transition to Industry 4.0 from the very beginning. After a staff meeting during which the opportunities of Industry 4.0 were presented, the management developed a digital strategy following a participative process involving representatives of the company's central divisions (Bosse, Hellge, & Schröder, 2019). From the perspective of intergenerational knowledge transmission, this means that new intergenerational, less hierarchically bound work situations and practices are emerging which might potentially create tensions and challenges for organizations.

INSIGHT 2. "Closing the knowledge gap" through reverse mentoring

In order to master the digital transformation, the French manufacturing company Vallourec, specialized in the fabrication of seamless steel tubes for the gas and oil market, decided to develop a reverse mentoring program (Vallourec, 2019). The reverse mentoring allowed to create regular trainings on digital and collaborative tools as well as on very technical topics like Big Data, 5G, artificial intelligence and Industry 4.0. In a similar vein, Roche, a biotech company based in Switzerland, launched a range of age-related initiatives, among them a reverse mentoring program. By teaching technological skills to seniors and business strategies to juniors, the program aims at "closing the knowledge gap" (Roche, 2018).

INSIGHT 3. A new human learning experience through the interconnection of virtual and real worlds

The German car manufacturer Porsche is currently using smart glasses even as a direct intermediary between human workers (Porsche, 2020). In case of critical troubleshooting, the augmented reality device allows technicians to connect with experts located elsewhere. Instead of error-prone exchanges or inefficient phone calls, the technician can take screenshots and send instructions in real-time. In addition to an increasing number of solutions and experiments in organizational practice, new research projects covering generational issues are being created. For instance, three universities and eight SMEs from the metal processing industry from the North-Eastern part of Germany launched a project called "KüSTE" which aims at experimenting with new digital methods (e.g., virtual 3D glasses) to capture and transfer valuable knowledge from retiring experts (IDW, 2021).

INSIGHT 4. Intelligent machines mastered with(out) human knowledge?

Traditionally, the only way to prevent energy waste in air compression systems was to inspect and maintain them manually. In order to reduce efficiency losses, however, companies can now rely on technologies like EcoPlant, a software as a service solution (IBM, 2019). A variety of sensors and intelligent devices allows the technology to collect relevant data from the compressors which is then processed and analyzed by an algorithm. Two options are then conceivable: 1) If human intervention is needed, the system sends a message with recommendations and suggestions for error handling to the responsible operations manager who is then in charge of the final maintenance procedure; 2) The technology runs in automatic mode which allows the system to take decisions and to control the equipment autonomously. For example, it can automatically close valves of a problematic compressor, without asking for human interference. From a generational perspective, such smart technology requires a rethinking of human roles at work, notably those of seniors. While the first option valorizes senior's expertise in decision-making, the second one shifts formerly experience-based actions and practices to intelligent machines.