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Review

Artificial intelligence in human factors and ergonomics: an overview of the current state of research

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Abstract
The development of artificial intelligence (AI) technologies continues to advance. To fully exploit the potential, it is important to deal with the topics of human factors and ergonomics, so that a smooth implementation of AI applications can be realized. In order to map the current state of research in this area, three systematic literature reviews with different focuses were conducted. The seven observation levels of work processes according to Luczak and Volpert (1987) served as a basis. Overall n = 237 sources were found and analyzed. It can be seen that the research critically deals with human-centered, effective as well as efficient work in relation to AI. Research gaps, for example in the areas of corporate education concepts and participation and voice, identify further needs in research. The author postulates not to miss the transition between forecasts and verifiable facts.

Keywords Artificial intelligence · Human factors and ergonomics · Overview · State of research

1 Introduction

The term artificial intelligence (AI) is not new. In 1956, the research discipline of AI was founded at the Dartmouth Conference in New Hampshire [1]. Since then, this technology has become a relevant application in academia as well as in private and work contexts. It has been called the next universal technology after the steam engine, electrification, and the Internet [2, 3]. The 2018 PR Neswire study forecasts the AI market to grow from USD 21.46 billion in 2018 to USD 190 billion by 2025 [4]. Moreover, from 2011 to 2017 alone, AI funding for startups increased 50-fold [5]. Chatbots or virtual agents as AI applications are currently used by many companies as a means of communication with customers. In production, in addition to digitization approaches, smart factories are also being enhanced with AI applications to make processes even faster and more effective.

Since there is no generally valid definition for human intelligence, there is no such definition for AI either. In research, a distinction is often made between weak and strong AI. This definition is difficult for current research in that there are no strong AI technologies yet and such a development must be awaited [6]. Often, the literature talks about methodologies of AI technologies, such as machine learning (ML) or deep learning (DL). For the current state of research presented in this paper, care was taken not to include studies in the field of automation only. In studies on AI, whether weak or strong, ML and DL were accepted.

However, in order to be able to use the potential of AI technologies in a meaningful way, including the aspects of human factors and ergonomics plays an important role [7–9]. These research areas aim to design a working system

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that is both humane and effective and efficient. Here effectiveness and efficiency represent the results of humane working conditions [7]. When work processes and conditions change through the use of AI applications, it is important to help shape such applications from an occupational science perspective, to accompany the changes and to develop and implement concepts for humane design. In the last few years, several AI failures have occurred that might have been prevented or minimalized if the above aspects had been considered before implementation. The lexalytics.com website features various failures, including chatbots, political gaffs, autonomous driving accidents, facial recognition mixups, and angry neighbors. A good example is a developed AI by Amazon that was supposed to support the selection of new employees and became anti-women based on the training data [10].

The question now arises as to what extent the aspects of human factors and ergonomics have already been integrated in the development and implementation of AI technology and where there is a need for research and action.

2 Material and methods

For this research, three systematic literature searches with different focuses were conducted according to Moher et al. [11]. For this purpose, a search string with keywords is defined and applied in the literature databases Ebsco and the database of the Technical University of Darmstadt, which in turn is linked to 13,359 database info systems. The seven levels of consideration of work processes of Luczak and Volpert were used as a basis for the keywords [7].

These levels have been combined into the seven levels of observation of work processes according to Luczak and Volpert, based on the seven levels of structure and the six levels of progression of the work process [7]. They serve as an outline of labor science issues and problems and aim to cover the problem area of "human work". Thus, for this literature study, the seven levels of consideration of work processes will be used as a categorization template. Search strings are chosen in order to map a complete overview of the state of work science research in the field of AI. Figure 1 provides an overview of these levels. A brief explanation of each level follows below.

Level seven "work and society" relates to the social context, dealing with legislation, economic production factors, cyclical and structural changes in the job market, vocational training concepts and inter-company activities of collective bargaining partners. Level six, which is below, deals with co-determination and employee representation. The focus here is on industrial relations. Under "forms of cooperation in working groups, " the division of labor, hierarchies, supervisor behavior, participation and codetermination rights, and human relations are examined and analyzed. The central level is "personal action and forms of work". At this level, the focus is on the working individual, so that a holistic view of work as a unity of motivational, volitional, qualification and social aspects is possible. Levels three to one are considered on both the human and the technical side: thus, level three "work activity and workplace" considers the mental processes at work as well as the system itself to realize the purpose of the system or the goal of work. On the penultimate level basic elementary physical as well as psychological functions of humans are examined in more detail. The levels of consideration are rounded off with the anatomical and physiological basis as well as environmental influences.

Due to the large number of levels and their subject areas, the systematic literature search was divided into three chronologically staggered investigations, whereby the literature for levels seven and six, levels five and four, and levels three to one was reviewed together. Thus, literature was searched for all levels in the period between October 2019 and November 2020, filtered according to German and English-language literature from the year 2010 onwards. This period was chosen because the discipline of ML had its breakthrough in 2010 and new research has been published. Table 1 gives an overview of the search strings used in each case.

The procedure of a systematic literature search according to Moher et al. specifies that after creating and entering the search string in a selected database, the hits are first sorted out according to titles and their keywords [11]. Then the literature results are thinned out again on the basis of the abstracts until finally the entire paper is read through. The selection criteria are determined in advance and are mostly determined by the keywords. If the studies refer to further interesting research results and these were not included in the selection by means of the search strings, these studies are additionally read and included in the presentation of the results (snowball search).

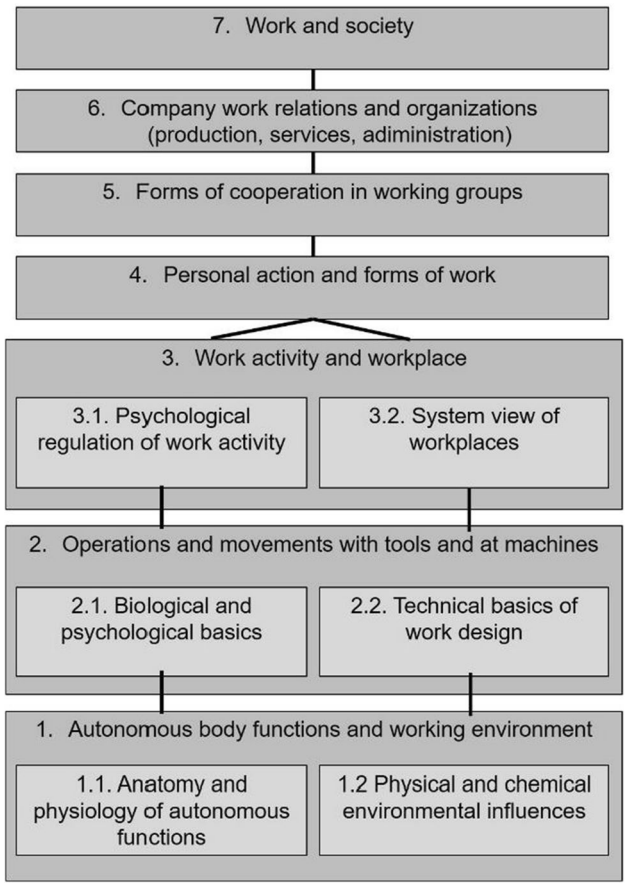

Fig. 1 Viewing levels of work processes according to Luczak and Volpert [63] ([7]; translated from German)

Table 1 List of search strings used for each literature search

Viewing levels of work processes	Search strings
Level 1 to 3	("artificial intelligence " OR AI OR "deep learning " OR "machine learning ") AND ("working environment " OR "bodily functions " OR biomechanics OR "energy conversion " OR metabolism OR "circadian rhythm " OR gender OR age OR noise OR vibration OR clime OR "coordination of movements " OR "body forces " OR "sensory organs " OR "human memory " OR anthropometry OR gripping OR "work design " OR usability OR "work activity " OR workplace OR "goal creation " OR planning OR "functional interaction " OR "temporal interaction ")
Level 4 and 5	("artificial intelligence " OR AI OR "deep learning " OR "machine learning ") *AND* ("worker motivation " OR "motivational effects" OR ("job satisfaction" AND (assessment OR improvement)) OR "work fatigue" OR "human worker satisfaction" OR "technophobes" OR (unemployment AND replacement) OR ("working conditions" AND employment) OR "employee qualification" OR ("employee training" AND learning NOT education NOT university) OR ("occupational training" AND intelligent) OR ("on-the-job-training" AND intelligent) OR "intelligent learning environment" OR ("social robotics" AND employee) OR "employee productivity" OR "employee performance " OR "worker safety" OR ("working conditions" AND human AND workplace NOT "human–robot") OR ("work environment" AND quality) OR "work system design") NOT politics NOT student
Level 6 and 7	("artificial intelligence " OR AI OR "deep learning " OR "machine learning ") AND (legislation OR "economic production factor " OR "changes in employment " OR "changes labor market " OR "vocational training concepts " OR "partners activities " OR codetermination OR "Staff representation" OR "Industrial relations")

For the search for German literature, the keywords were translated into German

3 Results

The results of the systematic literature searches for levels one to five have already been presented and published at a conference in Germany 2020 [12, 13]. Both study results are briefly presented below. Chapter 3.3 presents the results for levels six and seven.

3.1 Literature results for levels one to three

The search for levels one to three yielded N = 90 relevant sources, although some studies could not be assigned to only one level due to overlapping topics [12]. For level three "work activity and workplace", n = 61 papers could be assigned. The sources not only inform about AI applications, but also about work tasks and AI in the form of robots and chatbots, among other things. For example, the study by Wang et al. analyzes how an AI in the form of a robot can learn by interacting with a human [14]. For level two "Operations and movements with tools and at machines" n = 14 studies were found, which mainly dealt with the aspects of user interfaces as well as usability. Representative studies included medical training studies of surgeons practicing procedures using AI-based sensors and receiving direct feedback from the AI [15]. And finally, for level one "Autonomous body functions and working environment", n = 25 sources from the fields of ergonomics, production (environment) and cyper-physical-(socio) space (CPSS) could be analyzed. Studies on CPSS present optimal collaboration conditions [16, 17]. In the field of ergonomics, for example, a study is assigned to level one dealing with sensors on protective suits worn by firefighters and AI-based analysis of the data to predict human thermal sensation and the impact of this on work activity [18]. No research gaps were uncovered by means of the literature review.

3.2 Literature results for levels four and five

In the research for levels four and five, N = 114 relevant sources could be found. Compared to the first investigation, research gaps were identified here. For example, n = 49 study results were found for the "personal action and forms of work" level, in which the focus was on occupational safety and employee qualifications. Not only is training in the correct handling of AI-technologies for an efficient and safe use of these relevant in the qualification of employees, but also IT knowledge [19, 20]. As repetitive, routine tasks can be performed by AI in the future [21], employees need to be prepared for changes in work processes [22]: social skills increase in importance, as well as creativity, self-organization, and initiative, as these characteristics cannot be replaced by an AI [22, 23]. No research or its intentions was found for volitional aspects of work on the part of employees. Furthermore, it should be emphasized that the aspect of employee motivation tends to be underrepresented when interacting with AI-applications with n = 8 studies. Research gaps were found not only in level four, but also in the n = 65 papers in level five "forms of cooperation in working groups". Focus in these was on the impact on humans as well as the precondition of cooperation between AI and humans. For example, the preconditions mentioned were the safety of the application [24–27] as well as the possibility to detect correct errors [28, 29]. In Miller's study, subjects said they were afraid of using an AI application [30]. However, it is not only the deployment that can have an impact on people: in his study, Lefkowitz showed that in a game between robots and humans, losing had a negative impact on self-confidence, and subjects put less effort into winning after a certain point in the game [31]. So far, the topic of leadership as well as participation and voice has been neglected in the research. No sources were found on this topic. Due to overlapping topics in some of the studies found, some of these studies could not be assigned to just one level [13].

3.3 Literature results for levels six and seven

In the search regarding level six and seven, a total of N = 33 sources were found, of which n = 13 can be assigned to level six "company work relations and organizations". Table 2 summarizes the detected sources based on the keywords. The authors of these studies postulate that work will change with the use of AI: changes are expected in relation to work in general or work processes, resulting workload, interactions with technologies, employees and their employment relationship [32–35]. Potential is seen and expected in the area of communication as well as contact between employer and employee without a major administrative or human resources act [34]. Further improvements are expected in the area of supporting employees for better benefit choices, options for a diverse workplace in terms of health, wealth, and/or lifestyle [34]. In the area of interaction between different functions of organizations (executive efficiency) an increased productivity as well as effectiveness across the organization [36] is also assumed. In a survey conducted by Nankervis et al. N = 250 company representatives indicated that they expected work performance to improve, productivity to increase, as well as employees to be well supported when using AI-applications, but that they were not yet planning to use this technology in the near future [37]. In the meta-analysis by Hirsch, it is emphasized that some applications of AI-technologies are perceived suspiciously to alarmingly on the part of employees. Some of the considered AI-applications are so invasive that the manufacturers of these technologies recommend

Table 2 Research results for level 6

References	Keywords
Dodgson and Gann [32]	Change
Townsend [35]	Change
Place [34]	Change and possibilities
	Possibilities employees
Majumder [33]	Change and hurdle
Finch et al. [36]	Possibilities company
Hirsch [38]	Risks of use
Nankervis et al. [37]	Attitude/forecast on the part of the company
Herrmann and Nierhoff [40]	Heuristics and Recommendation
Vereinte Dienstleistungsgewerkschaft Bundesvorstand (ver.di) [39]	Co-determination, staff representation

companies to obtain the consent of employees before implementation [38]. For this reason, the united services trade union in Germany (ver.di) is also calling for the use of new smart technologies to benefit both the company and its employees, for more jobs to be created instead of lost, and for working conditions to be improved as a result. They also call for more co-determination rights for employees [39]. Herrmann and Nierhoff, for example, recommend that socio-technical solutions should continuously be developed with the participation of workers as well as management. Eight heuristics can be taken as a basis for the communication required for this between the individual workers as well as management: traceability and feedback for task processing, from flexibility of procedures to joint further development of the system, communication support for task processing and social exchange, task-bound information exchange for facilitating mental work, balance between effort and experienced success, compatibility between requirements, competence development and system properties, efficient task distribution for holistic goals, and supporting technology and resources for productive and error-free work [40].

For the "work and society" level, n = 23 sources were found. Table 3 summarizes the detected sources based on the keywords. One of those sources was a list from the German Bundestag from 2018, which includes 746 mainly German papers and articles on the topics: values and ethics, legal issues and regulation, democracy, state and society, security, surveillance and defense, research and education, economy, innovation and work, transport and mobility, medicine and care, environment and energy, arts and culture in relation to artificial intelligence [41].

For economic reasons, not all studies could be read for this report. In general, goals, targets as well as forecasts have been published on the part of politicians all over the world. In 2018, for example, the German government announced its intention to make Germany and Europe a leading AI location with the "Artificial Intelligence Strategy" in order to remain competitive. In addition, the goal is a responsible and public welfare-oriented development as well as use of AI [42]. In October 2016, the White House, the European Parliament as well as the British House of Commons published reports by showing their vision for preparing society for the use of AI. A subsequent analysis concludes that these adequately address ethical, social as well as economic aspects in the use of AI, but have not set out an overarching policy version and completely lack a long-term strategy for the development of a "good AI society" [43]. The study by van Berkel et al. compared the national policy documents on AI of 25 countries. It was shown that the following topics occupy the world [44]:

- Development strategy
- Infrastructure
- Private sector
- Public sector
- Data governance
- Ethical framework
- Education
- Healthcare
- Cooperation and alliances between public and private sector
- National, international and European issues

Table 3 Research results for level 7

References	Keywords
Buxmann and Schmidt [6]	Labor market
BMBF [57]	Labor market
Frey and Osborne [58]	Labor market
Grace et al. [59]	Labor market
PWC [53]	Labor market
	Economic production factor
Begleitforschung PAiCE [54]	Economic production Factor
Nature [55]	Economic production factor
LBBW Research [56]	Economic production factor
Nankervis et al. [37]	Production factor
Hartmann et al. [60]	Production factor
Ansari [16]	Vocational training concepts
Ansari and Seidenberg [17]	Vocational training concepts
Feigh et al. [26]	Vocational training concepts
Deutscher Bundestag [41]	Legislation and politics
Deutsche Bundesregierung [42]	Legislation and politics
Cath et al. [43]	Legislation and politics
Singh [45]	Legislation and politics
van Berkel et al. [44]	Legislation and politics
OECD [46]	Legislation and politics
Clarke [48]	Legislation and politics
Steels and López de Mantaras [51]	Legislation and politics
Park [47]	Legislation
O'Sullivan and Thierer [52]	Politics
van Nuenen et al. [49]	Discrimination
Santow [50]	Discrimination

The development of AI offers an unprecedented opportunity and challenge for humanity and a transformative impact on global health. An ethical, transparent, and responsible approach to AI development will result in AI turning data into contextual knowledge, conclusions, and impactful actions so that sustainable development goals can be achieved [45]. At the OECD conference in Paris in 2017, experts recognized that AI is transforming economic and social sectors deeper and faster than expected. The development of AI technologies is fast, they said, and so should be governments. To benefit from AI implementation, access to data must be improved and new policies adopted to adapt to AI in the workplace [46]. Threats to individual privacy, human security [47], and democratic principles must be addressed. Fairness and accountability are particularly in focus here. The formulation of common principles for AI in society is necessary. It can also be assumed that not all organizations act responsibly, so that an appropriate regulatory system for AI must be developed and applied [48]. An important issue here represents discrimination on the part of an AI: AI decision making can cause discriminatory harm to many vulnerable groups. Remedies are often suggested through increased transparency of these systems [49]. AI-ethics-frameworks can also be used for guidance [50]. At a 2017 workshop in Barcelona, a code of conduct for AI-researchers was drawn up as societal issues have developed around safety, reliability, robustness, fairness, as well as moral integrity due to the rapid development of AI. The code states agreements such as reliability of results, accountability, as well as preservation of human knowledge [51]. Thus, it should always be kept in mind that AI-based technologies may pose some serious risks, but policy makers should not freeze AI research and development due to fears, speculation, or an uncertain future [52]. After all, forecasts show that Germany's GDP could be up to 11.3% higher in 2030 due to the use of AI. The bulk of economic impact is expected to result from product enhancements for consumers [53]. In the next 5 years alone, additional gross value added of approximately €31.8 billion is calculated in the manufacturing sector in Germany due to AI [54]. Looking at the economic impact around the world, it is assumed that AI will add around 15 trillion USD to the global economy by 2030. This results in 15 trillion USD in new businesses, jobs, products, ways of working as well as leisure opportunities [55]. According to the analysis by LBBW Research, the following macroeconomic effects can be expected from AI [56]:

- A strong change in the business models of companies
- Higher productivity and thus higher real wages for employees
- A strong change in job profiles
- Higher unemployment of low-skilled labor
- Higher pressure on employees on the labor market and resulting lower inflation risks
- Increasing inequality in income distribution
- Winners are companies with the largest amounts of data and the greatest capacity to analyze data
- Social side effects, such as higher unemployment and consequently higher drug consumption and gambling addiction
- Increase in political risk due to higher dissatisfaction of employees via a higher acceptance of populist parties

Thus, experts give their assessment that there will be a structural and cyclical change in employment and the labor market in the future. In the future, there may no longer be a middle class; skilled workers are urgently needed. Jobs in which "a human hand" is needed, such as teachers, dentists, and clergy, will remain [6, 57–59]. By 2030, approximately 10% of jobs will be dependent on AI to some degree—so some jobs will be eliminated and new ones created [53]. The complex of topics "educational concepts" is still widely unexplored in the field of AI-technologies. Developers suggest that learning AI applications can enable mutual learning between humans and technology and potentially reduce employee anxiety [16, 17, 26].

4 Discussion

Based on the results of the three systematic literature searches reviews presented, it can be stated that the aspects of human factors and ergonomics have been widely taken into account in the development and implementation of AI technology in the presentation of the seven levels of work processes. Since AI-technologies are still in the early stages of development, many studies were found which forecast effects, authors aspects or opinions of enterprise representatives. This is especially the case for level six. In Germany, there are a number of research projects in this area that want to use survey studies to collect and gather initial concrete insights into the effects of AI on organizations. This is only possible because of the progressive development of AI technologies. The large-scale ACATECH study as well as the Competence Center for Work and AI in Darmstadt can be mentioned as examples. Politically, many goals were set but concrete implementation was neglected in the sources. This was especially evident in the studies that could be sorted into the more general levels, such as "work and society." The transition between forecasts and meaningful facts must be observed and not missed.

The research gaps that were uncovered by means of the research work should be clearly emphasized:

- Operational educational concepts
- The right of employees to have a say
- Employees' motivation and volitional aspects in the interaction of AI – applications
- Leadership in general
- Participation and voice in the AI-context

This could be due to the fact that AI is no longer classified as a trend with the onset of machine learning from 2010 and with Deep Learning and its success with AlphaGo in 2016. Developments have intensified [6, 61] and implementation projects are slowly progressing. In the future, however, research should focus more on the issues described above, especially those that affect employees. After all, even an implementation of a simple technology can fail due to a lack of acceptance or mistrust of the technology or the company [62].

The presented work does not represent a complete overview of the current research situation. New studies published after December 2020 could not be included. Furthermore, only sources were used that were written in German and English and were available as open access files. Studies with different keywords could not be included.

It can be discussed whether the classification of the search strings into the seven levels of consideration of work processes, as suggested by Luczak and Volpert [63], is useful for the presentation of the current state of research. This holds true especially for the field of human factors and ergonomics [7]. Some studies could be assigned to more than one level. In particular, the studies found in the literature search on level seven "work and society" and level six "company work

relations and organizations" could have been additionally assigned to the lower levels, especially in the aspect of changes and opportunities. Consequently, a selectivity was not given. Since work research is an interdisciplinary science, the core of human factors and ergonomics is assigned to levels three to five in German-speaking countries. Occupational physicians and work technologists are assigned more to the lower levels, i.e. micro-ergonomics, sociologists and economists to the higher levels, i.e. macro-ergonomics [7]. For further and more in-depth research, studies that can be assigned to levels three to five in relation to AI should be looked at more closely. The other levels should be looked at more closely by colleagues from other disciplines.

5 Conclusion

The presented work provides an overview of the current state of research on the aspects of human factors and ergonomics in the development and implementation of AI technologies. Research gaps were identified in the areas that primarily concerned employees and their opinions. Research needs were highlighted and it was postulated not to miss the transition between predictions to verifiable facts.

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Competing interests The authors declare no competing interests.

References

1. Dartmouth College. Summer research project on artificial intelligence (Vox of Dartmouth). Hanover: Dartmouth College; 1956.
2. Agrawal AK, Gans JS, Goldfarb A. Economic policy for artificial intelligence. In: Lerner J, Stern S, editors. Innovation policy and the economy. Chicago: University of Chicago Press; 2018. p. 139–59.
3. Varian H. Artificial intelligence, economics, and industrial organization. Cambridge: University of Chicago Press; 2018.
4. Hampleton Artificial Intelligence Report. M&A market report 1H 2018; 2019. https://www.hampletonpartners.com/de/reports/artificial-intelligence-report/. Accessed 21 Oct 2020.
5. CB Insights. Top artificial intelligence trends to watch in 2018; 2018. https://www.cbinsights.com/research/report/artificial-intelligence-trends-2018/. Accessed 21 Oct 2020.
6. Buxmann P, Schmidt H. Künstliche Intelligenz: mit Algorithmen zum wirtschaftlichen Erfolg. Berlin: Springer; 2019.
7. Schlick C, Bruder R, Luczak H. Arbeitswissenschaft. Berlin: Springer; 2018.
8. Bengler K, Schmauder M. Digitalisierung. Berlin: Springer; 2016. p. 75–6.
9. Wickens CD, Gordon SE, Liu Y. An introduction to human factors engineering. Upper Saddle River: Pearson Prentice Hall; 1988.
10. Lexalytics.com (2020) Stories of AI failure and how to avoid similar AI fails. https://www.lexalytics.com/lexablog/stories-ai-failure-avoid-ai-fails-2020. Accessed 21 Oct 2020.
11. Moher D, Liberati A, Tetzlaff J, Altman DG. The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7):e1000097. https://doi.org/10.1371/journal.pmed1000097.
12. Petrat D. Künstliche Intelligenz im Arbeitskontext – ein aktueller Forschungsstand zum Einfluss und zur Anwendung von Künstlicher Intelligenz am Arbeitsplatz. In: Digitaler Wandel, digitale Arbeit, digitaler Mensch? Dokumentation des 66. Arbeitswissenschaftlichen Kongresses, Dortmund, GfA-Press, GfA Frühjahreskongress 2020, TU Berlin, 16.03. bis 18.03.2020, ISBN 978-3-936804-27-0; 2020
13. Petrat D. Künstliche Intelligenz im arbeitswissenschaftlichen Kontext – eine definitorische Einordnung anhand menschenzentrierter Betrachtungsebenen von Arbeitsprozessen. In: Digitaler Wandel, digitale Arbeit, digitaler Mensch? Dokumentation des 66.

Arbeitswissenschaftlichen Kongresses, Dortmund, GfA-Press, GfA Frühjahreskongress 2020, TU Berlin, 16.03. bis 18.03.2020, ISBN 978-3-936804-27-0; 2020.
14. Wang W, Li R, Chen Y, Diekel ZM, Jia Y. Facilitating human-robot collaborative tasks by teaching-learning-collaboration from human demonstrations. IEEE Trans Autom Sci Eng. 2018;16(2):640–53.
15. Cavallo F, Sinigaglia S, Megali G, Pietrabissa A, Dario P, Mosca F, Cuschieri A. Biomechanics-machine learning system for surgical gesture analysis and development of technologies for minimal access surgery. Surg Innov. 2014;21(5):504–12.
16. Ansari F, Khobreh M, Seidenberg U, Sihn W. A problem-solving ontology for human-centered cyber physical production systems. CIRP J Manuf Sci Technol. 2018;22:91–106. https://doi.org/10.1016/j.cirpj.2018.06.002.
17. Ansari F, Seidenberg U. A portfolio for optimal collaboration of human and cyber physical production systems in problem-solving. In: International association for development of the information society; 2016. p. 311–5.
18. Pendzich M, Bleyer T, Kupschick S. Intelligente Schutzausrüstung lernt maschinell – gebrauchstaugliche neue Informationstechnologie. Zeitschrift für Arbeitswissenschaft. 2013;67(3):169–74.
19. Ghislieri C, Molino M, Cortese CG. Work and organizational psychology looks at the fourth industrial revolution: how to support workers and organizations? Front Psychol. 2018;9:1–6.
20. Pankow G. Maschinelles Lernen lernen. Produktion. 2018;57(18):8–9.
21. Baggio B, Omana N. AI and big workplace changes. Workforce Solut Rev. 2019;10(2):30–3.
22. Wiesinger A, Klier J, Daub M. Weiterbildung ist die Antwort. Personalwirtschaft. 2018;45(12):44–5.
23. Bughin J, Lund S, Hazan E. Automation will make lifelong learning a necessary part of work. Harvard business review, 2–4; 2018. https://hbr.org/2018/05/automation-will-make-lifelong-learning-a-necessary-part-of-work. Accessed 21 Oct 2020.
24. Crenze U. Echt stark! Der Digital Workplace als KI-gestützter Information Hub. In: DOK. Das Magazin für digitale Dokumenten- und Unternehmensprozesse 2019; 2019. p. 10–4.
25. Criado N, Argente E, Botti V. Open issues for normative multi-agent systems. In: AI Communications. 2011; 24(3): S. 233–264. http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=67088466&site=ehost-live. Accessed 21 Oct 2020.
26. Feigh KM, Miller MJ, Bhattacharyya RP, Ma M, Krening S, Razin Y. Shifting role for human factors in an `unmanned' era. Theor Issues Ergon Sci. 2018;19(4):389–405. https://doi.org/10.1080/1463922X.2017.1328713.
27. Reimann J, Sziebig G. The intelligent factory space—a concept for observing, learning and communicating in the digitalized factory. IEEE Access. 2019;7:70891–900. https://doi.org/10.1109/ACCESS.2019.2919340.
28. Furkel D. Hallo wie kann ich helfen? In: personalmagazin—impulse zur Gestaltung der Arbeitswelt; 2019. (21):34–7.
29. Rupprecht C, Laina I, Navab N, Hager GD, Tombari F (Hg.). Guide me: interacting with deep networks. In: 2018 IEEE/CVF conference on computer vision and pattern recognition. Proceedings. Place of publication: Los Alamitos, CA, USA; Salt Lake City, UT, USA. Country of Publication: USA: IEEE Computer Society; 2018. http://search.ebscohost.com/login.aspx?direct=true&db=inh&AN=18326314&site=ehost-live. Accessed 21 Oct 2020.
30. Miller CC. Will you lose your job to a robot? Silicon Valley is split, N.Y. Times; 2014. p. 39.
31. Lefkowitz M. In competition, people get discouraged by competent robots; 2019. http://news.cornell.edu/stories/2019/03/competition-people-get-discouraged-competent-robots. Accessed 21 Oct 2020.
32. Dodgson M, Gann D. Artificial intelligence will transform universities. Here's how. "World economic forum annual meeting; 2017. https://www.weforum.org/agenda/2017/08/artificial-intelligence-will-transform-universities-here-s-how/. Accessed 21 Oct 2020.
33. Majumder M. Technology as work and work as technology. Int J Hum Capital Inf Technol Prof IJHCITP. 2016;7(1):20–34.
34. Place A. AI may be missing link to upgrade benefits enrollment: Artificial intelligence can ease the stress of picking benefits and provide personalized options for a diverse workplace. Employee Benefit News. 2020. 34(2): pN.PAG-N.PAG. 1p; 2020.
35. Townsend K. A future for IR academics? 2018 AIRAANZ presidential address; 2019. pp. 1-5. https://doi.org/10.1080/10301763.2018.1510301.
36. Finch G, Goehring B, Marshall A. The enticing promise of cognitive computing: high-value functional efficiencies and innovative enterprise capabilities. Strat Leadership. 2017;45:26–33.
37. Nankervis A, Connell J, Cameron R, Montague A, Prikshat V. 'Are we there yet?' Australian HR professionals and the Fourth Industrial Revolution; 2019.
38. Hirsch PB. Tinker, tailor, soldier, spy. J Bus Strat. 2019. https://doi.org/10.1108/JBS-04-2019-0077.
39. Vereinte Dienstleistungsgewerkschaft Bundesvorstand (ver.di). Künstliche Intelligenz und gute Arbeit gestalten. Wir mischen uns ein, gestalten, regeln - mit Euch gemeinsam! Innovation und Gute Arbeit, Politik und Planung. Berlin; 2019.
40. Herrmann T, Nierhoff J. Heuristik 4.0-Heuristiken zur Evaluation digitalisierter Arbeit bei Industrie-4.0 und KI-basierten Systemen aus soziotechnischer Perspektive; 2019.
41. Deutscher Bundestag. Künstliche Intelligenz - Gesellschaftliche Verantwortung und wirtschaftliche, soziale und ökologische Potentiale. Literaturauswahl, ISSN 1435-4039; 2018.
42. Deutsche Bundesregierung. Strategie Künstliche Intelligenz der Bundesregierung; 2018. www.ki-strategie-deutschland.de. Accessed 21 Oct 2020.
43. Cath C, Wachter S, Mittelstadt B, Taddeo M, Floridi L. Artificial intelligence and the 'good society': the US, EU, and UK approach. Sci Eng Ethics. 2018;24(2):505–28.
44. van Berkel N, Papachristos E, Giachanou A, Hosio S, Skov MB. A systematic assessment of national artificial intelligence policies: Perspectives from the Nordics and beyond. In: Proceedings of the 11th nordic conference on human-computer interaction: shaping experiences, Shaping Society; 2020. p. 1–12.
45. Singh JA. Artificial intelligence and global health: opportunities and challenges. Emerg Top Life Sci. 2019;3(6):741–6.
46. OECD. AI: intelligent machines, smart policies, OECD conference in Paris, France, on 26–27 October 2017, OECD Digital Economy Papers, August 2018, No.270; 2018.
47. Park S. The role of government in science and technology legislation to prepare for the era of artificial intelligence. In: Proceedings of law and political sciences conferences (No. 7909652). International Institute of Social and Economic Sciences; 2018.
48. Clarke R. Regulatory alternatives for AI. Comput Law Secur Rev. 2019;35(4):398–409.

49. van Nuenen T, Ferrer X, Such JM, Cote M. Transparency for whom? Asessing discriminatory artificial intelligence. Computer. 2020;53(11):36–44.
50. Santow E. Emerging from AI utopia. Science. 2020;368:9.
51. Steels L, López de Mantaras R. The Barcelona declaration for the proper development and usage of artificial intelligence in Europe. AI Commun. 2018;31(6):485–94.
52. O'Sullivan A, Thierer A. Counterpoint: regulators should allow the greatest space for AI innovation. Commun ACM. 2018;61(12):33–5.
53. PWC. Auswirkung der Nutzung von Künstlicher Intelligenz in Deutschland; 2018. www.pwc.de/ki-potential. Accessed 21 Oct 2020.
54. Begleitforschung PAiCE, iit-Institut für Innovation und Technik in der VDI/VDE Innovation + Technik GmbH (2018). BMWi-Studie Potenziale der Künstlichen Intelligenz im produzierenden Gewerbe in Deutschland, Juli2018.
55. Nature. International AI ethics panel must be independent. Nature 2019; 572(7770):415. https://doi.org/10.1038/d41586-019-02491-x
56. LBBW Research. Makroökonomische Effekte künstlicher Intelligenz. Erste Annäherungen an einen Strukturbruch. Aufsichtsbehörde Europäische Zentralbank (EZB), Frankfurt; 2017.
57. BMBF. ZukunftsMonitor IV: Wissen schaffen – Denken und Arbeiten in der Welt von morgen; 2017. https://www.bmbf.de/files/zukunftsmonitor_Wissen-schaffen-denken-und-arbeiten-in-derwelt-von-morgen.pdf. Accessed 21 Oct 2020.
58. Frey C, Osborne M. The future of employment: how susceptible are jobs to computerisation?; 2013. https://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf. Accessed 21 Oct 2020.
59. Grace K, Salvatier J, Dafoe A, Zhang B, Evans O. "When will AI exceed human performance? Evidence from AI Experts"; 2017. https://arxiv.org/pdf/1705.08807.pdf. Accessed 21 Oct 2020.
60. Hartmann EA, Hornbostel L, Thielicke R, Tillack D, Wittpahl V. Wie sieht die Zukunft der Arbeit aus?. Ergebnisbericht zur Umfrage „Künstliche Intelligenz und die Zukunft der Arbeit ", Institut für Innovation und Technik Berlin; 2017.
61. Chen JX. The evolution of computing: AlphaGo. Comput Sci Eng. 2016;18(4):4–7.
62. Abel J, Hirsch-Kreinsen H, Wienzek T. Akzeptanz von Industrie 4.0. Abschlussbericht zu einer explorativen empirischen Studie über die deutsche Industrie. München: acatech; 2019.
63. Luczak H, Volpert W. Arbeitswissenschaft. Kerndefinition – Gegenstandskatalog – Forschungsgebiete. RKW-Verlag, Eschborn; 1987.