Required Competence Development in Higher Education to Manage the Digital Transformation in the Industry

Paricipatory Action Research with Stakeholders Applying the Analytic Hierarchy Process

Fabian Lindner
Faculty of Business Administration and Engineering
Zittau/Görlitz University of Applied Sciences
Zittau, Germany
0000-0001-8249-534X

Daniel Winkler
Faculty of Business Administration and Engineering
Zittau/Görlitz University of Applied Sciences
Zittau, Germany
daniel.winkler@hszg.de

Sophia Keil
Faculty of Business Administration and Engineering
Zittau/Görlitz University of Applied Sciences
Zittau, Germany
sophia.keil@hszg.de

Preprint

***Abstract*—In this paper, we investigate the process of curriculum design in higher education to address the need for the development of digital competences of industrial engineers. In the light of digital transformation, an increasing amount of pedagogy literature, policy papers, and practitioners call for the development of digital competences. However, concrete approaches to tackle this issue in practice are still scarce. We followed a participatory action research approach together with stakeholders of a university of applied sciences to develop the foundations of a curriculum to equip engineering graduates with additional managerial, social, and psychological insights and approaches to succeed in digital transformation or Industry 4.0 projects in manufacturing companies. In several workshops with undergraduates, faculty, alumnae, researchers, and industry representatives the needs and prospective job profiles of such digital transformation managers were defined. The therefore required competences were prioritized applying the Analytic Hierarchy Process (AHP) by comparing the necessary knowledge, skills, as well as attitudes and values (KSA). The results first show difficulties in establishing a common understanding of required competences between the stakeholders due to the complexity of the notion of digital transformation. Nevertheless, the stakeholder involvement process and the AHP as decision support can serve as a suitable basis for the design process of engineering curricula, as well as in other contexts.**

Keywords—competences, digital transformation, higher education, stakeholders, Analytic Hierarchy Process (AHP)

I. Rationale to Develop Competence-Driven Industry 4.0 Curricula and Research Questions

Digital transformation in general, and automation and digitalization in specific play a significant role in industry. These efforts culminate today in what is also known under the term Industry 4.0 (I4.0) [1]: the networking and communication of all units involved in production in real time—man and machine. Due to the associated, sometimes far-reaching changes in the entire production process, the question of which competences are required of the employees plays an important role in this context as well.

Several authors have dealt with this topic in different ways. Hecklau et al. [2], for example, derive the necessary core competences of employees based on the challenges that companies are facing in the sense of I4.0. Similarly, Butschan et al. [3] also deal with the question of which competences are required in the production area in I4.0, whereas Keil et al. [4] examine such competences specifically in the context of semiconductor manufacturing. However, the question of how these competences are to be built up is inevitably linked to these considerations of competence requirements in industry. In this context, universities, among others, play an important role.

However, real examples from higher education about the process of transferring the need for specific competences into concrete programs are still rare. This is why in the present contribution we investigate (1) the design process of a respective course of study under stakeholder involvement at a university of applied sciences and (2) the relevance of certain digital competences to be developed within the envisioned curriculum. More in detail, we are especially concerned with the following research question (RQ): How can the competence profile of a digital transformation manager be derived as the basis for a respective curriculum design and how does it look like?

II. Theoretical Foundations in Industry 4.0 and Related Competence Requirements

A. Industry 4.0 and Digital Transformation

The term I4.0 was introduced in 2011 by the high-tech strategy of the German government and stands for the intelligent linkage of machines and processes using information and communication technology (ICT) [5]. It is considered the next level of manufacturing with implications for value creation, business models, downstream services, and work organization [1]. Similar notions in other countries are Internet of Things, Internet of Everything, Smart Factory, Smart Production, Industrial Internet [6] or Second Machine Age [7].

The work underlying this publication was supported by the iDev40 project. The iDev40 project is funded by ECSEL Joint Undertaking (JU) under Grant Agreement No. 783163. The JU is supported by the EU program for research and innovation Horizon 2020. The project is co-funded by the consortium partners and grants from Austria, Germany, Belgium, Italy, Spain and Romania. Parts of the work have also been funded by the German Federal Ministry of Education and Research (BMBF) under the grant number 03WIR2704. The responsibility for the content of this publication lies with the authors and does not necessarily reflect the opinion of the JU or the BMBF.

Strongly connected to I4.0 are also the notions of digitization, digitalization, and digital transformation. Whereas digitization refers to the one-to-one transformation of analogue to digital processes [8], digitalization stands for the implementation of digital technology and includes its impact on the way of work in the company [9]. Digital transformation, finally, stands for a strategic business transformation using organizational changes as well as the implementation of digital technologies [10].

These automation and digitalization efforts in the industry are expected to further imply a general shift in workers' manual task characteristics from monotonous towards more complex, knowledge-intensive jobs [11]. This entails, for example, changing qualification demands [12], but also stress or uncertainty [13]—for both shop floor and office workers.

Thus, recent developments even call for further enhancements towards Industry 4.h or Industry 5.0, focusing on human-centered manufacturing, where "technology serves people, rather than the other way around [and] the worker is more empowered and the working environment is more inclusive" [14].

B. Digital Competence Requirements and Higher Education

Concerning changing qualification demands on human work in an I4.0 and digital transformation context, further trainings and education programs to develop necessary competences have been described or evaluated, for example, in [15–17]. While Lindner et al. [15] describe an overall engineering-to-order process divided into individual teaching scenarios in a learning factory for undergraduate students in industrial engineering, Lensing and Friedhoff [16] present the conceptual design of an internet of things (IoT) lab to educate mechanical engineers of different proficiency. In doing so, both [15] and [16] ground their considerations in I4.0 competence requirements or profiles to be addressed. Terkowsky et al. [17] follow the same approach, but contrast the derived competence profile from literature with an existing remote laboratory to conclude a close connection to engineering fundamentals, but mourn a lack of interdisciplinary learning scenarios.

Also, the Organisation for Economic Co-operation and Development (OECD) [18] proposes a more general framework to foster the development of competences, that are defined as "more than just the acquisition of knowledge and skills; it involves the mobilisation of knowledge, skills, attitudes and values to meet complex demands". As well, Vuorikari et al. [19] call for digital competences for the general citizenship, and give several examples.

III. Applied Action Research and Multi-Criteria Decision Analysis

A. Participatory Action Research with Stakeholders

To analyze the course design process, we followed a participatory action research (PAR) approach. PAR is not one methodology, but in general refers to a research process where questions or problems are dealt with that are of relevance for the participants, following steps of collaborative action to make real-world changes as well as its reflection, and situating the experiences and results in a broader research context [20]. However, while the subjectivity of PAR is a strength due to its capability to draw from authentic experiences, it is also a weakness at the same time, as it embeds the risk that the findings might be of relevance only to the specific context.

In our case, twelve stakeholder representatives—including the authors—from different German universities, faculties, small and medium-sized (SMEs) as well as large enterprises (LEs), and in different functions (Table I) were jointly developing the basis of a new course of study at the Zittau/Görlitz University of Applied Sciences (HSZG), Germany called digital transformation management by applying different techniques, and to sufficiently address the industry's need for changed skillsets of future engineers.

TABLE I. STAKEHOLDER WORKSHOP PARTICIPANTS (OWN TABLE)

No.	Affiliation	Function
1	HSZG	Vice-rector
2	HSZG	Dean and faculty for business administration
3	HSZG	Faculty for mechanical engineering
4	HSZG	Faculty for computer science
5	HSZG	Faculty for industrial engineering
6	HSZG	Researcher in indstrial engineering
7	HSZG	Researacher in engineering pedagogy
8	HSZG	Researcher in operations management
9	Semiconductor manufacturer (LE)	Senior specialist factory integration
10	Software developer (SME)	Head of innovation management
11	Turbine manufacturer (LE)	Software developer and HSZG alumnus
12	University of applied sciences	Graduate student and HSZG alumnus

As means of collaboration and joint development of the curricula, workshop formats were chosen and different creative techniques to ease, for example, brainstorming. But one focal technique applied and investigated within the PAR process was the analytic hierarchy process (AHP) as described in the following Sub-Section III.B.

B. Analytic Hierarchy Process for Competence Ranking

Furthermore, for the purpose of prioritizing the competences to be induced within the envisioned program, the AHP [21] was applied and investigated concerning its suitability in this context. The AHP helps to systematically support decision-making processes. To the best of our knowledge, the AHP has hardly ever been used or examined in the context of competences to be imposed in university teaching. As an instrument for systematization, traceability and thus simplification of decisions within a group, it also appears to be helpful for the participatory design of a curriculum involving the relevant stakeholders.

The AHP was developed by Saaty [21]. The decision criteria are structured hierarchically and combined into categories—if necessary. The method owes its name to its hierarchical character, systematized approach, and mathematical-analytical evaluation. Each AHP starts with the formulation of a question or problem, on the basis of which relevant criteria for the solution are collected. In a second step, each of these criteria is compared to every other criterion of the same category or hierarchy level and its relative importance is evaluated on a scale from one to nine. The results of the pairwise comparisons are recorded in a matrix. The weightings of the individual criteria are calculated using

Preprint

TABLE II. DEVELOPED VISION FOR THE NEW COURSE OF STUDIES (OWN TABLE)

Vision Statement			
Train digital transformation managers who are able to shape the digital transformation in small and large production companies in a reflective, goal-oriented and sustainable manner.			
Target group	***Needs***	***Product***	***Value***
• Innovation-oriented and open-minded students • Students working in a company • Students with several years of work experience • Students with an engineering background (mechanical engineering, computer science, electrical engineering, ...) • Management trainees	• Methods and know-how for the reflected, responsible and successful digital transformation of production companies of all sizes and industries • Development and implementation of sustainable, future-proof strategies for economy and society in a globalized world • Personal development and leadership qualities	• Master's program in digital transformation management • Can be studied while working • Possibility of taking certification courses • Practical, project-related and problem-oriented training and cooperation with regional and national companies • Always at the edge of science through links to national and international Industry 4.0 research projects	• Experts and leaders for digital technologies, business models, products, services, markets and transformations in a global context • Critical reflection and targeted, precisely tailored use of automation and digitization instead of blind faith in technology • Holistic, sustainable acting in terms of economy, society and environment

the eigenvector and eigenvalue, and possible inconsistencies in the evaluation of the pairwise comparisons are pointed out. If such inconsistencies are identified, the pairwise comparisons in question must be reconsidered and the respective selections adjusted. The result is an overall hierarchy that shows the importance of the individual criteria for achieving the desired goal.

In comparison to similar methods with the aim of simplifying complex decisions and making them more rational—such as utility analysis—the AHP is credited with greater accuracy due to its detailed and differentiated approach in the assessment of alternatives and its elaborate evaluation logic. However, at the same time, this is accompanied by a higher effort. Due to the non-trivial evaluation and the overall necessary high effort in the survey, it can be helpful to use freely accessible software tool support by, for example, AHP-OS [22] or Decisor [23].

Based on the previous work in [4, 24, 25], a first AHP hierarchy has been constructed with the aim of forming a weighted set of competences for future industrial engineers [26]. To this end, various competence requirements for the digital transformation in business and society were identified on the basis of existing literature [4, 25]. In addition, standardized and semi-standardized surveys in manufacturing companies were conducted on competences in the context of I4.0 [24]. When the collected literature and data was analyzed, some of the mentioned competences were more suitable to be assigned to knowledge, skills, or attitudes and values (KSA)—among others, also in accordance with the OECD [18]. Thus, competences imply the interaction of KSA in order to meet complex requirements [18]. For this reason, the KSA categorization was adopted for the criteria of the first level of the hierarchy [26].

After the final consolidation of the identified aspects of KSA from the literature and the surveys, the criteria of the second and final hierarchical level were finally formed [26]. The hierarchy in [26] then built the basis for further discussion and refinement with respect to digital transformation managers in our workshops.

IV. RESULTING STAKEHOLDER VISION AND COMPETENCE PROFILE

A. *Establishment of a Joint Understanding and Vision*

In the second workshop—since September 2020—to develop the new curriculum, a vision board was created in November 2020 to visualize the group consent on the overall goal: the new course of studies to educate digital transformation managers at the HSZG (Table II). This instrument proved to be helpful throughout the subsequent workshop meetings until July 2021 to refer back to and to adapt the overall vision, if major changes were agreed upon. Most importantly, the relevant target group was identified as engineering graduates, offering them further training opportunities in part-time concerning methods for successfully dealing with the digital transformation and Industry 4.0.

B. *Competence Profile of a Digital Transformation Manager*

After the first rounds of discussion and clarification of the notions of the competence hierarchy in [26], it was agreed in the third workshop in March 2021 upon the description of the categories and sub-categories as shown in Table III. Afterwards, the participants were individually asked to pairwise rate the categories using the AHP-OS [22] with the ultimate goal to envision and rate a competence profile of a digital transformation manager. The aggregated group results of the criteria's relative importance are depicted in Fig. 1. The results stress the focus on skill development, especially the innovation capability of the graduates.

V. DISCUSSING THE PRACTICAL IMPLICATIONS FOR HIGHER EDUCATION

Applying PAR throughout the first three workshops to develop a new course of study for digital transformation management—until the evaluation of the resulting competence profile in March 2021—allowed new insights about stakeholder involvement in the curriculum design and the efficiency and effectiveness of the AHP as decision basis for further developments of courses in higher education.

While applying the PAR, the composition of the workshop participants gave the impression to be quite well balanced in

TABLE III. COMPETENCE CATEGORIES AND DESCRIPTIONS (OWN TABLE)

Competences	**“The concept of competency implies more than just the acquisition of knowledge and skills; it involves the mobilisation of knowledge, skills, attitudes and values to meet complex demands” [10].**
Knowledge	***“Facts and figures, concepts, ideas, and theories that are already established and further the understanding of a particular field or subject area” [19].***
Management knowledge	Management expertise, especially in change, innovation, project, strategy, lean, stakeholder, risk, leadership and human resources management, and related standards and norms.
Engineering knowledge	Expertise in engineering, particularly mechanical, computer, and electrical engineering, and in automation and digitization technologies, computer and data security, and related standards and norms.
Methodological knowledge	Knowledge especially related to methods for process analysis, business model development, technology assessment, risk assessment, and innovation, problem-solving, and decision-making techniques; and related standards and norms.
Business process knowledge	Knowledge especially related to business processes in manufacturing: metaprocesses, process models; and related to business models; associated standards and norms.
Skills	***“Execute processes and apply existing knowledge to achieve results” [19].***
Dealing with ICT as well as data	Dealing with ICT as well as data/(digital) information, in particular also with artificial intelligence
Communication and dialogue skills, cooperation and teamwork skills	Communication and dialog skills, cooperation and teamwork skills (also in human-machine interaction)
Analytical skills, ability to question and evaluate critically, decision-making skills, problem/conflict resolution skills	Analytical skills, ability to (critically) question and evaluate, decision-making ability, problem/conflict-solving ability
Intercultural skills/global thinking skills	Intercultural skills, internationality, dealing with diversity, languages, ability to think globally
Ability to act and think sustainably/ethically (economically, ecologically, social)	Ability to act and think sustainably/ethically (economically, ecologically, social)
Inter- and transdisciplinary acting and thinking, as well as systems thinking	Inter- and transdisciplinary acting and thinking, as well as systems thinking or holistic thinking (interdependencies of different systems and effects)
Ability to transfer knowledge, ability to expand own knowledge, presentation skills and storytelling, motivation skills	Ability to teach or to document, share, transfer knowledge; ability to tell stories (storytelling) or to present (in virtual and real environment); ability to motivate (oneself and others)
Ability to innovate	Ability to innovate
Attitudes and values	***“Willingness to act or respond to ideas, people, or situations, and appropriate mind-sets” [19].***
Emotional intelligence	Ability to empathize, social and emotional intelligence
Creativity and innovative spirit as well as curiosity	Creativity, imagination, innovative spirit and out-of-the-box thinking, curiosity
Mobility, flexibility, openness, adaptability (in way of working and thinking)	Mobility, flexibility, openness, adaptability (in way of working and thinking)
Ethical ideas and sustainable attitude	Ethical ideas and sustainable attitude
Willingness to learn and develop	Willingness to learn and develop

terms of internal participants of the HSZG (two thirds) as well as external stakeholders. Thus, the voluntary and continuous participation of the company representatives and alumni was especially gratefully acknowledged by the faculty. Therefore, no unacceptability of outside experts could be observed that would have impacted the behavior of the group. Also, due to these circumstances and the family atmosphere at the HSZG—because of its small size and low teacher-student ratio—the likelihood of biases due to existing power relations among the participants can also be considered to be low.

Nevertheless, the fluctuation of the number of participants between the workshops and the long period without any meeting between November 2020 and March 2021—owed to the second COVID-19 lockdown in Germany—required recurrent discussions to regain a joint understanding of the goals at each workshop, despite protocols of each meeting. However, the developed vision board in the second workshop helped to mitigate these phenomena. The vision board facilitated as well the envisioning of a digital transformation manager and thus, eased the rating of the respective competence profile by the participants using the AHP.

In terms of the application of the AHP, even more time than a one-day workshop to establish a sound common understanding of the KSA concepts would have been beneficial, before diving into the rating of the AHP hierarchy. This is due to the fact the AHP requires quite some time for explanation, but more importantly, the more frequently and often the participants are coming together and discussing the curriculum, the better the common understanding of all the relevant KSA gets. This facilitates its subsequent evaluation tremendously but can take quite some time and effort to ensure a mental map as similar as possible between all participants.

The contribution of the resulting competence profile lies less in the selected and described KSA themselves, but primarily on its rating. While the presented KSA might not be very different to similar competence profiles as in [16, 17]—

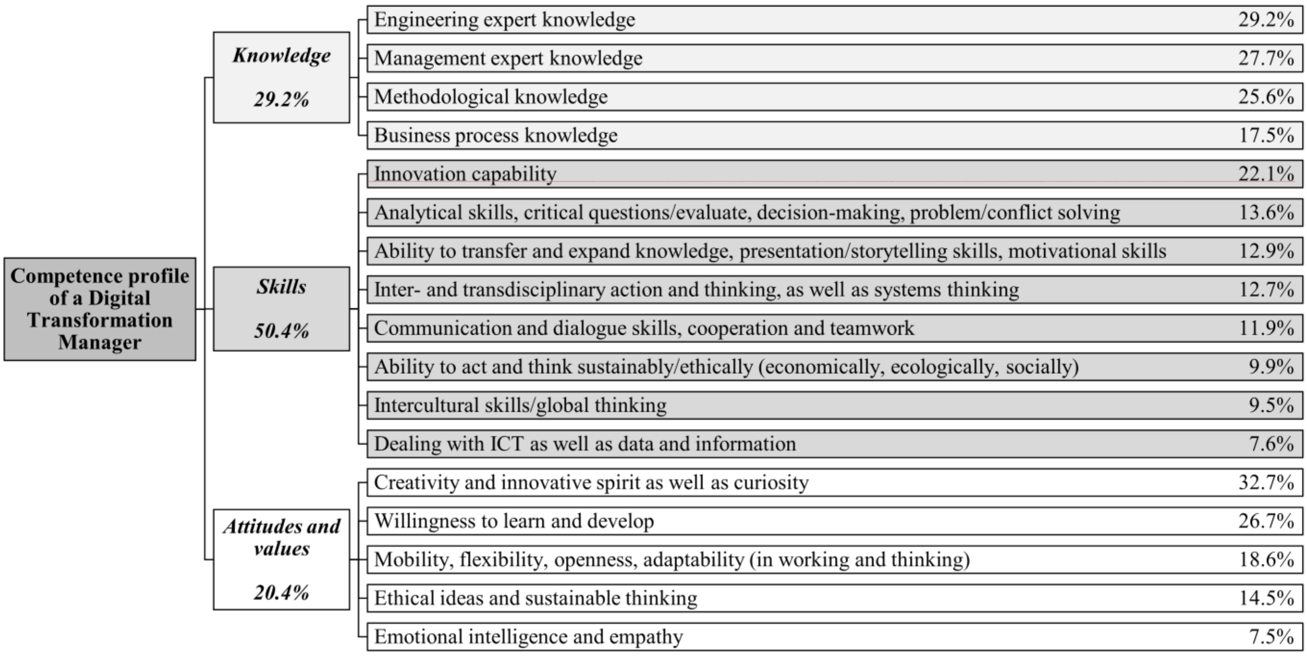

Fig. 1. Competence hierarchy for an envisioned digital transformation manager with relative importance of the criteria per category (own figure).

where they even might be described more in detail—, or as already argued in [24], our competence profile is able to make a distinction between the importance of different KSA. This is of great practical relevance and allows, for example, to plan respective actions accordingly. In our case, as the envisioned digital transformation course of study is meant for graduated engineering students, it makes sense to prioritize accordingly which KSA should be induced with the new curriculum. This means, for example, that engineering expert knowledge might be more or less neglected in the design considerations, whereas the following ranked knowledge—management expert knowledge—might be especially focused on, and so on and so forth. At the same time, attitudes and values such as emotional intelligence and empathy might be difficult to be induced in higher education per se and could therefore be neglected. Nevertheless, as we suppose that these are still relevant for a successful digital transformation manager, such attitudes and values could be considered to be kinds of prerequisites to be eligible for inscription into this course of study.

VI. Concluding Remarks and Future Directions

The digital transformation of industry and society's demand for sustainable economic activity are placing ever new demands on the training of skilled personnel. Many companies, especially SMEs, are not able to meet these challenges effectively and efficiently with their own continuing education programs. Therefore, it is of particular importance to be able to offer skilled personnel a complementary opportunity for further training outside their company. In these companies, for example, special fields of activity such as digital transformation management, which cannot be trained in their own company or for which internal training is too cost-intensive, can be provided with further training. The world of work will continue to change within the framework of digital transformation. It will become “more flexible, networked, dynamic and diverse” [27]. In order to meet these future requirements, continuing education programs are needed that enable employees to develop digital competences in addition to professional content, among other things. By making well-trained specialists available for the regional labor market, SMEs and LEs are to be supported with regard to digital change. Without qualified employees, companies will not be able to maintain leading positions in international markets. In order to create an innovative and market-oriented training program, it is necessary to determine the needs of those LEs and SMEs. A continuing education program developed in this way allows for a quick and flexible adaptation of the educational offer to provide innovative, demand-oriented and evidence-based support and supplement the basic education at universities and regional educational institutions.

So far, the involvement of the stakeholders from different universities, faculties, SMEs, LEs, as well as in different functions has proved to be beneficial in the development of an interdisciplinary course of study like digital transformation management. The AHP can also be considered to be a helpful tool for further decision support to design the focusses of the teaching modules, prioritize and chose the KSA to address, as well as to allocate resources and manage trade-offs at the faculty and the university accordingly to finally implement the course of study.

Our study has also certain limitations. First of all, due to the specific composition and small size of the participating group, the external validity of the findings is not unrestricted. Furthermore, despite the fact that the AHP was known to some of the participants as a quite common tool in management and engineering, this might be different in other domains. Therefore, the already long but necessary process to establish a common understanding of the KSA might become even longer and effortful due to higher requirements in explaining the functioning of the AHP itself. Nevertheless, also in our case, it is likely that still different understandings of different KSA exist between the stakeholders that hamper the interpretability of the AHP results and is related to the fact that qualitative phenomena are being quantified—this plays an even bigger role for such a complex notion as digital transformation. One opportunity to still deal quantitatively with the individual understandings of digital transformation and KSA could be the application of fuzzy sets [28]. Furthermore, different classification or clustering techniques to create categories among KSA might be feasible in addition. Furthermore, our KSA are quite generic and/or encompass many notions, while other competence profiles might be more concrete. This is another downside of the use of the AHP, as an increase of the criteria to evaluate will tremendously increase the efforts for the decision-makers.

However, besides the application of the AHP results for prioritizing teaching focusses, it could also be used for comparison or benchmarking the program with similar ones. Subsequently, within our curriculum design process, the teaching formats supporting the competence goals will have to be developed and the concept could be tested with surveys and feedback from students, alumni, and/or potential future employers that have not been part of our stakeholder group, so far.

Even though the results firstly have to be evaluated solely within the context of the specific university of applied sciences under investigation, findings about the design process and actions taken within could be beneficial to be transferred to similar university contexts—also from other disciplines. We therefore call for the application, dissemination, and discussion of comparable approaches also in other domains of study to share further experiences in the design of new curricula.

Acknowledgment

We thank the organizers and participants of the University4Future workshops at the Zittau/Görlitz University of Applied Sciences—especially the working group for digital transformation management—for enabling this research process. Further, we are grateful for the substantial feedback and helpful suggestions of the five anonymous reviewers to improve the final paper.

References

[1] H. Kagermann, W. Wahlster, and J. Helbig, "Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Final Report of the Industrie 4.0 Working Group," Securing the future of German manufacturing industry, 2013.

[2] F. Hecklau, M. Galeitzke, S. Flachs, and H. Kohl, "Holistic Approach for Human Resource Management in Industry 4.0," *Procedia CIRP*, vol. 54, pp. 1–6, 2016, doi: 10.1016/j.procir.2016.05.102.

[3] J. Butschan, V. Nestle, J. C. Munck, and R. Gleich, "Kompetenzaufbau zur Umsetzung von Industrie 4.0 in der Produktion," in *Betriebswirtschaftliche Aspekte von Industrie 4.0*, M. Seiter, L. Grünert, and S. Berlin, Eds., Wiesbaden: Springer Fachmedien Wiesbaden, 2017, pp. 75–110, doi: 10.1007/978-3-658-18488-9_4.

[4] S. Keil, F. Lindner, J. Moser, R. von der Weth, and G. Schneider, "Competency Requirements at Digitalized Workplaces in the Semiconductor Industry," in *Lecture notes in electrical engineering, Digital Transformation in Semiconductor Manufacturing*, S. Keil, R. Lasch, F. Lindner, and J. Lohmer, Eds., Cham: Springer International Publishing, 2020, pp. 88–106, doi: 10.1007/978-3-030-48602-0_9.

[5] S. Keil, F. Lindner, G. Schneider, and T. Jakubowitz, *A Planning Approach for an Effective Digitalization of Processes in Mature Semiconductor Production Facilities*. In Veröffentlichung., 2019.

[6] H. Kagermann, R. Anderl, J. Gausemeier, G. Schuh, and W. Wahlster, Eds., *Industrie 4.0 im globalen Kontext: Strategien der Zusammenarbeit mit internationalen Partnern*. Munich: Herbert Utz, 2016.

[7] E. Brynjolfsson and A. McAfee, *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*. New York, NY: Norton, 2014.

[8] Gartner, Inc., *Gartner IT Glossary: Digitization.* [Online]. Available: https://www.gartner.com/it-glossary/digitization/ (accessed: Sep. 20 2021).

[9] M. Muro, S. Liu, J. Whiton, and S. Kulkarni, "Digitalization and the American workforce," 2007.

[10] MIT Center for Digital Business and Capgemini Consulting, "Digital Transformation: A Roadmap for Billion-Dollar Organizations," Findings from Phase 1 of the Digital Transformation Study Conducted by the MIT Center for Digital Business and Capgemini Consulting, 2011.

[11] G. Campatelli, A. Richter, and A. Stocker, "Participative Knowledge Management to Empower Manufacturing Workers," *International Journal of Knowledge Management*, vol. 12, no. 4, pp. 37–50, 2016, doi: 10.4018/IJKM.2016100103.

[12] R. von der Weth and U. Starker, "Integrating motivational and emotional factors in implementation strategies for new enterprise planning software," *Production Planning & Control*, vol. 21, no. 4, pp. 375–385, 2010, doi: 10.1080/09537280903453893.

[13] E. M. Meijer, M. H. W. Frings-Dresen, and J. K. Sluiter, "Effects of office innovation on office workers' health and performance," *Ergonomics*, vol. 52, no. 9, pp. 1027–1038, 2009, doi: 10.1080/00140130902842752.

[14] European Commission. Directorate General for Research and Innovation., "Industry 5.0: towards a sustainable, human centric and resilient European industry," 2021, doi: 10.2777/308407.

[15] F. Lindner, D. Winkler, K. Mühlan, U. Wendt, and S. Keil, "Learn to Shape the Digital Transformation: The Design Approach of a Learning Factory for Industrial Engineers," *SSRN Journal*, 2021, doi: 10.2139/ssrn.3858409.

[16] K. Lensing and J. Friedhoff, "Designing a curriculum for the Internet-of-Things-Laboratory to foster creativity and a maker mindset within varying target groups," *Procedia Manufacturing*, vol. 23, pp. 231–236, 2018, doi: 10.1016/j.promfg.2018.04.022.

[17] C. Terkowsky, S. Frye, and D. May, "Using Constructive Alignment to Evaluate Industry 4.0 Competencies in Remote Laboratories for Manufacturing Technology," in *Cross Reality and Data Science in Engineering*, Cham, 2021, pp. 603–613.

[18] OECD, Ed., "The Future of Education and Skills: Education 2030," The Future We Want, 2018.

[19] R. Vuorikari, Y. Punie, S. Carretero, van den Brande, and Lieve, *DigComp 2.0: The Digital Competence Framework for Citizens*. Update Phase 1: The Conceptual Reference Model. EUR 27948 EN. Luxembourg: Publication Office of the European Union, 2016, doi: 10.2791/11517.

[20] P. Reason and H. Bradbury-Huang, *The SAGE Handbook of Action Research: Participative Inquiry and Practice*. London: SAGE Publications, 2007.

[21] T. L. Saaty, "A scaling method for priorities in hierarchical structures," *Journal of Mathematical Psychology*, vol. 15, no. 3, pp. 234–281, 1977, doi: 10.1016/0022-2496(77)90033-5.

[22] K. D. Goepel, "Implementation of an Online Software Tool for the Analytic Hierarchy Process (AHP-OS)," *IJAHP*, vol. 10, no. 3, 2018, doi: 10.13033/ijahp.v10i3.590.

[23] R. M. Czekster, H. J. de Carvalho, G. Z. Kessler, L. M. Kipper, and T. Webber, "Decisor: A Software Tool to Drive Complex Decisions with Analytic Hierarchy Process," *Int. J. Info. Tech. Dec. Mak.*, vol. 18, no. 01, pp. 65–86, 2019, doi: 10.1142/S0219622018500360.

[24] F. Lindner, K. Mühlan, D. Winkler, F. Naumann, and S. Keil, "Die Bedeutung "klassischer" Kompetenzen in der digitalen Transformation," 2019, doi: 10.13140/RG.2.2.35748.83846.

[25] S. Keil, K. Mühlan, F. Lindner, and D. Winkler, "Digitale Kompetenzen in der Hochschullehre: 10.000 Schritte in den Fußstapfen eines Pickers," in *Wege zu technischer Bildung, Technische Bildung im Kontext von 'Digitalisierung'/ 'Automatisierung': Tendenzen, Möglichkeiten, Perspektiven*, M. Petersen and G. Kammasch, Eds., Berlin: IPW, 2020.

[26] F. Lindner, D. Winkler, K. Mühlan, and S. Keil, "Digitale Kompetenzen für zukünftige Wirtschaftsingenieurinnen und -ingenieure: Ein Stakeholderranking mithilfe des analytischen Hierarchieprozesses (AHP)," Online-Pre-Conference 2020 der 15. Ingenieurpädagogischen Regionaltagung 2021, 2020, doi: 10.25819/ubsi/7837.

[27] vbw – Vereinigung der Bayerischen Wirtschaft e.V., Ed., "Digitale Souveränität und Bildung: Gutachten," Münster: Waxmann, 2018, doi: 10.25656/01:16569.

[28] L. A. Zadeh, "Fuzzy sets," *Information and Control*, vol. 8, no. 3, pp. 338–353, 1965, doi: 10.1016/S0019-9958(65)90241-X.

Preprint