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Virtual reality for prospective and process-related competence modeling—piloting a participatory approach and investigating user acceptance of the applied VR-tool

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Abstract

In times of digitalization, it is important to derive competence requirements in relation to future digitalized business processes. Enabling to present these processes in an illustrative and experienceable way, Virtual Reality (VR) may offer special advantages for prospective and process-related competence modeling (PCM) and to include employees as competence modelers. In order to investigate these potential advantages, a VR-based PCM approach is piloted and compared with a conventional PCM approach. In order to identify concrete VR-attributes that may be specifically supportive for VR-based PCM, user acceptance of the applied VR-tool has been evaluated.

Results show that the realistic visualization and interaction possibilities provided by VR support a prospective and process-related analysis focus during competence modeling. This way, employees are enabled to identify future competence requirements with regard to single process steps. Comparisons with the conventional PCM approach demonstrate that the prospective and process-related competence models developed in VR provide a higher level of detail concerning the number of identified competence requirements. In the course of user acceptance evaluation, concrete VR-attributes are derived that are most supportive for participatory PCM (e.g. 3D visualization, perceived immersion).

Practical Relevance: VR offers a space for experiencing new business processes, thus enabling employees to conduct PCM. By integrating employees' expertise, required future competences can be derived validly. On this basis, appropriate measures for effective competence modeling can be implemented in the organization.

Keywords Digitalization · Virtual Reality · Competence Modeling · Participation · User acceptance

Virtual Reality zur prospektiven und prozessbezogenen Kompetenzmodellierung – Pilotierung eines partizipativen Vorgehens und Untersuchung der Nutzerakzeptanz des angewendeten VR-tools

Zusammenfassung

In Zeiten der Digitalisierung ist es wichtig, Kompetenzanforderungen in Bezug auf zukünftig digitalisierte Geschäftsprozesse herzuleiten. Virtual Reality (VR) ermöglicht es, diese Prozesse anschaulich und erlebbar darzustellen. Daher bietet die VR besondere Potenziale für die prospektive und prozessbezogene Kompetenzmodellierung (PKOM) und die Einbindung der Mitarbeitenden als Kompetenzmodellierer:innen. Um diese potenziellen Vorteile zu untersuchen, wird ein VR-basierter PKOM-Ansatz pilotiert und mit einem konventionellen PKOM-Ansatz verglichen. Zur Herleitung von VR-Eigenschaften, die besonders unterstützend in diesem Kontext sind, wurde die Nutzerakzeptanz des eingesetzten VR-tools evaluiert.

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Die Ergebnisse zeigen, dass die realitätsnahen Visualisierungs- und Interaktionsmöglichkeiten der VR einen prospektiven und prozessbezogenen Analysefokus unterstützen. Auf diese Weise werden Mitarbeitende dazu befähigt, zukünftige Kompetenzanforderungen in Bezug auf einzelne Prozessschritte zu identifizieren. Der Vergleich mit dem konventionellen PKOM-Ansatz zeigt, dass die in der VR entwickelten prospektiven und prozessbezogenen Kompetenzmodelle einen höheren Detaillierungsgrad hinsichtlich der Anzahl der identifizierten Kompetenzanforderungen aufweisen. Im Zuge der Evaluation der Nutzerakzeptanz werden konkrete VR-Eigenschaften herausgearbeitet, die für den PKOM-Ansatz besonders nützlich sind (z. B. 3D-Visualisierung, wahrgenommene Immersion).
Praktische Relevanz: Die VR ermöglicht ein Erleben zukünftiger Geschäftsprozesse und befähigt Mitarbeitende auf diese Weise für die prospektive und prozessbezogene Kompetenzmodellierung. Durch die Einbindung der Mitarbeiterexpertise lassen sich zukünftige Kompetenzanforderungen valide ableiten und entsprechende Maßnahmen für eine wirksame Kompetenzentwicklung umsetzen.

Schlüsselwörter Digitalisierung · Virtual Reality · Kompetenzmodellierung · Partizipation · Nutzerakzeptanz

1 Introduction

Digitalization refers to a process of change resulting from the introduction of new digital technologies into business processes (e.g., Bengler and Schmauder 2016; Mache and Harth 2020). This also leads to changes in employees' workflows and relating competence requirements (Hulla et al. 2019; Schwarzmüller et al. 2018). The way competence requirements actually change primarily depends on the digitalization context of the individual company (e.g., Ganz et al. 2019; Harteis 2018). The introduction of new information and communication technologies (ICT) often implies quicker and denser processes that gain in complexity and interconnectedness (Harteis 2018). This may lead to new competence requirements in terms of information dissemination and -processing, communication and collaboration, teamwork, decision making, or problem-solving using ICT (e.g., van Laar et al. 2019, 2017). However, no general statement can be made as to whether digitalized work will require higher or lower levels of qualification (Harteis 2018). Probably, both directions will occur. While some digital assistance systems provide all necessary work instructions, other systems need to be carefully controlled by the worker. In this case, high technical and process-related knowledge is demanded (Harteis 2018). Thus, when preparing employees for their future digital work, the company-specific scenario of digitalization (e.g., Ganz et al. 2019; Harteis 2018) as well as the affected business- or work processes (e.g., Hegmanns et al. 2019) should be carefully considered. PCM approaches may provide a fruitful method as they allow deriving future competence requirements with regard to specific business- or work processes (cf., Hegmanns et al. 2019). In this context, employee participation can be a critical success factor as they provide in-depth process- and task-related knowledge (e.g., Robinson et al. 2007). In order to mobilize employees' knowledge, future business processes should be conveyed and explained as clearly as possible. However, conventional approaches often use paper-based process graphs that are still too abstract and complex for employees to understand (e.g., Leyer et al. 2021). VR-technology is a promising response to this challenge, as it allows to provide three-dimensional (3D) representations of real or imaginary environments that enable users to interact with virtual objects and to simulate a series of actions in an intuitive manner (Davies 2004; Wolfartsberger et al. 2018). This way, future business processes can be visualized in a more detailed and realistic way (e.g., Oberhauser et al. 2018; Oberhauser and Pogolski 2019).

When applying VR in the context of competence management, there may be initial skepticism among employees (Müller et al. 2022). Thus, understanding users' perception and acceptance of the virtual setting is a prerequisite to predict its potential advantage (cf., Carrion et al. 2021). Previous research already identified various criteria forecasting user acceptance of VR-applications (e.g., Brunkow and Hub 2018; Janzik 2022). With regard to competence management, it has been emphasized that the ease of use as well as user's emotional immersion and enjoyment are important acceptance driving factors (Carrion et al. 2021). When being met to an adequate degree, these factors can pave the way for effective educational settings (cf., Carrion et al. 2021). In view of these learning-supportive attributes, VR-based methods of competence assessment and development have a long scientific tradition. In fact, there exists a plenitude of research exploring the potential of immersive VR-tools. In this context, the focus is mainly placed on evoking authentic user behaviors that serve to derive individual competence characteristics or development needs (e.g., Akdere et al. 2021; Hickman and Akdere 2018; Jensen et al. 2017; Paszkiewicz et al. 2021). However, the potential of VR to facilitate the identification of future competence requirements and development needs and to integrate employees as active competence modelers remains largely understudied.

Facing this research gap and reflecting on the fact that competence requirements should be identified in a prospective and process-related way in times of digitalization, this study investigates the potential advantages that VR may provide for participatory PCM. In view of the above-mentioned advantages that VR offers for educational settings (e.g., emotional immersion and enjoyment) as well as for business process understanding (e.g., realistic visualizations), we assume that VR also provides special advantages for participatory PCM. In order to examine this assumption, a VR-based PCM approach is piloted in three German small and medium-sized enterprises (SMEs). The VR-based PCM approach transfers validated methods and instruments of PCM to a VR-representation. During expert interviews, employees explain their future work activities and identify future competence requirements with regard to specific business process steps. The VR-tool used for this purpose virtually maps employees' future process steps using a three-dimensional (3D) business process modeling notation (in our case, it is the established Business Process Model and Notation approach, BPMN). On the basis of employees' job descriptions and identified competence requirements, prospective and process-related competence models are derived. In order to outline whether VR is actually advantageous for participatory PCM, the competence models obtained during the VR-based expert interviews are compared with the competence models that emerged from a conventional PCM approach (using paper-based process graphs). The focus of analysis is placed on contrasting the models' level of detail concerning the number of identified competence requirements. To identify concrete VR-attributes that are most supportive for participatory PCM, user acceptance evaluation is carried out. For this purpose, both standardized usability criteria (cf., Kähler et al. 2019) as well as VR-specific acceptance criteria are analyzed (cf., Brunkow and Hub 2018).

2 Theoretical background

2.1 The concept of competence

In the organizational context, competences are defined as observable working behaviors that base on the application of a set of knowledge, skills, abilities, and other characteristics (KSAOs) being relevant for effective job performance (e.g., Aamodt 2010; Roberts 2005; Woods and Hinton 2017). Particularly widespread and recognized is the distinction between four job-related competence dimensions comprising professional, methodological, social and personal competences (Schaper 2019). Professional competences describe specific knowledge and skills that are required to successfully realize professional tasks (e.g., product knowledge). Methodological competences refer to cognitive and metacognitive skills that are necessary for autonomously dealing with complex working tasks (e.g., problem-solving skills) (Schaper 2019). Social competences include skills of behaving appropriately in situations of social interaction (e.g., communication skills) (Kauffeld and Grote 2019). Personal competences are individual dispositions, such as attitudes and motives, that influence employees' working behavior (e.g., assuming responsibility). Personal competences also include the ability of independently controlling one's own professional behavior (e.g., learning ability) (Schaper 2019). A popular instrument for operationalizing and measuring the four job-related competence dimensions mentioned above, is the "Competence Reflection Inventory" (CRI, Kauffeld 2021). The CRI represents a theory-based questionnaire that measures associated competence sub-dimensions using an eleven-level answer scale. Another widely used instrument is the "competence atlas" (Heyse and Erpenbeck 2009; Heyse 2010), which provides 64 sub-dimensions to operationalize similar job-related competence dimensions. These encompass technical and methodological, activity- and action, social-communicative, as well as personal competences (e.g., Heyse and Erpenbeck 2009; Heyse 2010). In addition to the above-mentioned competence dimensions, digital competences are becoming increasingly important in recent times (e.g., Ferrari 2012). Since the competence dimensions of the digital competence construct can largely be classified into the four job-related competence dimensions of technical, methodological, social and personal competence, digital competence is interpreted as a cross-sectional competence in this article (e.g., Blumberg and Kauffeld 2021). In order to measure and develop individuals' digital competences, the "Digital Competence Framework for Citizens 2.1" (DigComp 2.1, Carretero et al. 2017) has been established in the context of a well-known EU-project. The DigComp 2.1 provides five competence dimensions that include information and data literacy, digital content creation, the capacity to communicate and collaborate using digital technologies, the skill to ensure data safety, and the ability to solve problems using digital technologies (Carretero et al. 2017).

2.2 Competence modeling

2.2.1 Traditional approaches for competence modeling

Competence modeling aims at identifying and describing competences that are required for effective job performance (cf., Albertsen et al. 2010). Competence models summarize these performance-relevant competences (e.g., KSAOs) and thus are linked to the organizational strategy (e.g., Campion et al. 2011). The listed competences are usually subdivided into relating competence sub-dimensions (Schaper 2009). Within these sub-dimensions, different competence levels are distinguished. The competence levels can be used to map employees' individual competence characteristics at different stages (Schaper 2009). This way, it is possible to distinguish between high and average performers (Campion et al. 2011). Generally, there exist three traditional approaches of competence modeling. The one-size-fits-all-approach aims at developing one competence model that is relevant for the entire organization or a broad range of jobs (e.g., all managerial jobs). In contrast, the single-job-approach focuses on developing specific competence models for each individual job. The VR-based PCM approach presented in this article bases on the multiple-job-approach (Mansfield 1996). The multiple-job-approach is a mixture of the above-mentioned one-size-fits-all-approach and the single-job-approach. Thus, the resulting competence models comprise both overarching as well as job-specific competence requirements (Mansfield 1996). In terms of data collection, the one-size-fits-all-approach uses competence models that are already available in the organization or can be obtained from scientific literature (e.g., Mansfield 1996). In contrast, the single-job-approach derives competence requirements directly from expert interviews being conducted with job holders and/or their managers. Again, the multiple-job-approach uses a kind of mixture of both methods. In particular, competence requirements are derived using a common set of predefined competences as well as methods of job analysis in order to differentiate these predefined competences (e.g., Mansfield 1996; Sonntag 2007). In general, job analysis encompasses activities for systematically analyzing and describing work activities, worker attributes, and work contexts (Sackett and Laczo 2003).

2.2.2 Approaches for prospective and process-related competence modeling

Supplementing these traditional forms of competence modeling, prospective and process-related approaches for competence modeling become increasingly important. Specifically with regard to the context of digitalization, PCM approaches offer an efficient way to identify future competence requirements more precisely (cf., Hegmanns et al. 2019). The approaches presented in Robinson et al. (2007) and Yang et al. (2006) can be seen as precursors of PCM. Robinson et al. (2007) developed an approach for prospectively identifying future competence requirements. Here, employees' quantitative perceptions of the most required future competences are identified using a predefined competence questionnaire. The identified competence requirements are then differentiated in the context of critical incident interviews (cf., Flanagan 1954). Yang et al. (2006) developed a procedure for process-oriented competence analysis. Here, business processes are decomposed into their single process steps and relevant competence requirements are mapped to these process steps afterwards. Ranking the mapped competences by frequency enables to identify core competences in a process-oriented way. The VR-based PCM approach piloted in this article combines the prospective and process-related analysis focus. In particular, it draws on the PCM approach presented in Depenbusch et al. (2021). In this preceding approach, future competence requirements are identified by applying the multiple-job-approach in a prospective and process-related manner. In the course of expert interviews with job holders and supervisors, work activities as well as critical incidents (Flanagan 1954) occurring in the future digitalized business processes are first explained by the employees. Second, respective competence requirements are identified using a printed competence inventory. In order to maintain a process-related focus of analysis, a printed BPMN-process graph is presented to the interviewees. Based on the data gathered in these expert interviews, prospective and process-related competence models are derived. The pilot runs in Depenbusch et al. (2021) show that the prospective and process-related derivation of future competence requirements demands a deep process understanding on behalf of the employees. This is also the case when the identified competence requirements should be mapped to the single process steps in order to create prospective and process-related competence models. Thus, the prospective and process-related competence models have been created by work- and occupational psychologists and checked afterwards by the interviewees. Specifically, when the focus is placed on rather hypothetic or future business processes, employees need a profound capacity for abstraction. This can be particularly demanding when only schematic, paper-based process graphs are presented (cf., Oberhauser et al. 2018). As a response to this challenge, this article pilots an approach that utilizes VR as a facilitator for identifying and documenting future competence requirements with regard to single process steps. In order to outline whether VR is actually advantageous for this purpose, the competence models resulting from the VR-based approach are compared with those obtained in Depenbusch et al. (2021).

2.3 Using VR for the participative approach of prospective and process-related competence modeling

The underlying assumption of this article is that VR provides special advantages to facilitate participatory PCM. In this study, we associate participation with the empowerment of employees to become active competence modelers. One way to include employees as competence modelers is to strengthen their comprehension of future business processes. Chapter 2.3.1 thus outlines VR-attributes that have already been identified by previous research as particularly advantageous in terms of fostering business process understanding. Drawing on these insights, this study aims at identifying further concrete VR-attributes that are beneficial for participatory PCM. For this purpose, user acceptance evaluation is carried out. As already mentioned, understanding employees' perception and acceptance of VR will give valuable insights for predicting its potential advantages. Chapter 2.3.2 first defines the concept of user acceptance. Afterwards, standardized usability criteria as well as VR-specific acceptance criteria used in our study are presented.

2.3.1 VR as a tool for employee participation

Employee participation comprises activities that give employees the possibility to participate and assume responsibility (Dombrowski et al. 2018). In this study, we associate participation with the empowerment of employees to become active competence modelers. Since business process understanding is a central precondition, we draw on previous studies that already investigated how a VR-environment should be designed to promote employees' business process understanding. These are in particular studies on participatory and collaborative business process modeling and management (e.g., Oberhauser and Pogolski 2019). Here, VR serves as a tool to empower employees (and even those who are not familiar with interpreting abstract and complex process graphs) to intuitively design and evaluate business- or work processes (e.g., Zenner et al. 2020). In this context, it has already been revealed that the translation of conventional business process modeling notations to a VR-representation (e.g., 3D-BPMN) offers special advantages to support employees' process understanding (e.g., Oberhauser and Pogolski 2019; Zenner et al. 2020). These advantages result from specific attributes of VR, such as the ability to visualize complex business process structures in a more holistic and illustrative manner (Oberhauser et al. 2018; Oberhauser and Pogolski 2019), or to facilitate access and storage of process-related information (e.g., Betz et al. 2008).

2.3.2 User acceptance of VR-tools

Drawing on these insights, further advantages of VR for employee participation can be derived in the course of user acceptance evaluation. In the context of IT, user acceptance is described as the willingness of individuals to employ information technology for the task it is designed for (Dillon and Morris 1996; Wahdain and Ahmad 2014). The model mostly employed for predicting user acceptance is the technology-acceptance model (TAM, Davis et al.1989). The TAM gives general feedback on the ease of use and usefulness of a system. However, the TAM does not provide specific information about important attributes of the system itself. Therefore, Wixom and Todd (2005) developed the User Satisfaction—Technology Acceptance Model (US-TAM) connecting the TAM with user satisfaction (US) literature. US literature identifies various system- and information quality attributes and thus allows evaluating the technical artefact itself in terms of supporting user acceptance (Wixom and Todd 2005). Since this study aims at exploring VR-attributes that mainly drive user acceptance and thus potentially provide advantages for participatory PCM, we specifically refer to literature grounding on the US-TAM. In particular, we apply the "catalog of criteria for forecasting user acceptance" by Brunkow and Hub (2018) as primary theoretical foundation in order to select the acceptance criteria to be considered in this study. The information quality attributes listed in this catalog comprise, e.g., the customizability of virtual texts and images or the relevance of the presented information for the respective context of use (cf., Brunkow and Hub 2018). The system quality attributes refer to, e.g., the level of immersion or the experienced interactivity or the system usability (cf., Brunkow and Hub 2018).

Usability describes the extent to which a system can be applied in a certain context of use to achieve definite goals in an effective, efficient and satisfactory manner (Kähler et al. 2019). In this study, usability of the applied VR-tool is evaluated using a questionnaire that grounds on the universally standardized norm ISO 9241. The particular focus is placed on the performance measures defined in ISO 9241-11 as well as on the dialog principles for usable human-machine-interaction (HMI) presented in ISO 9241-110. The performance measures are directed to the system's effectiveness, efficiency, and user satisfaction (cf., Kähler et al. 2019). The dialog principles comprise, e.g., the system's task appropriateness, self-descriptiveness or fault tolerance (Kähler et al. 2019). As the characteristic attributes of VR (e.g., immersion, interaction) imply a special form of human-machine-interaction (HMI) (e.g., Martens 2016), we formulated the criteria presented in ISO 9241-11 and ISO 9241-110 with regard to our investigation context. For example, the criteria task appropriateness (describing that the functions of the system are based on the characteristic properties of the task in question) (e.g., Kähler et al. 2019) is formulated in the usability questionnaire as follows: "The functionalities of the VR-tool are appropriate for answering the interview questions."

Although being formulated with regard to our investigation context, the usability criteria applied in our study still maintain a high degree of standardization. This way, we want to supplement the VR-specific acceptance criteria (cf., Brunkow and Hub 2018) with criteria that are more comprehensible for individuals without VR experiences. This target group may be more familiar with common usability criteria, such as those presented in ISO 9241. Due to maintaining a high degree of standardization, the usability

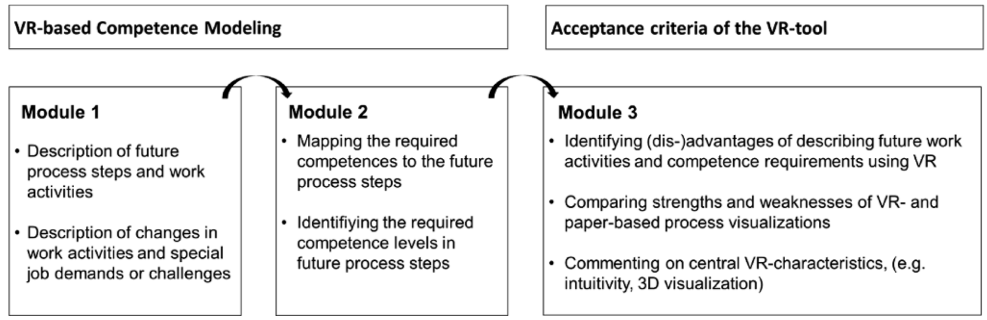

Fig. 1 Procedure of the VR-based expert interviews conducted in the three SMEs
Abb. 1 Vorgehen im Rahmen der VR-basierten Expert:inneninterviews in den drei KMU

results can additionally be used for comparison with usability findings obtained for non-VR methods of competence modeling.

3 Methods

3.1 Sample

The participatory, VR-based PCM approach was piloted in the context of nine semi-structured VR-based expert interviews. The interviews were conducted in three SMEs that participate in the research project “Socio-digital innovation through participatory business process modeling in virtual spaces (SoDigital)”. Each SME engages in digitalizing certain business- or work processes. These digitalization projects also form the use cases of our study. SME 1 belongs to the sector of metal construction and plans to integrate digital tablets in its welding process to facilitate internal communication. Employees will be able to directly report upcoming work activities or product- and machine faults to other business areas. SME 2 is part of the glass wholesale sector and intends to implement a digital system in its inventory management process that records incoming and outgoing products and documents free or full storage yards. This way, employees will be able to manage inventory and storage yards more efficiently. SME 3 belongs to the food industry and aims at using digital tablets in its quality control process for transparently recording and evaluating quality control parameters. In this context, employees enter their measured product parameters into a digital tablet. Table 1 shows the business sectors of the three SMEs, their approximate total number of employees and the interviewees’ jobs.

Table 1 Sample of the expert interviews
Tab. 1 Stichprobe der Expert:inneninterviews

	SME 1	SME 2	SME 3
Business sector	Metal construction	Glass wholesale	Food industry
Number of employees (approx.)	65	40	200
Jobs of the interviewees	Project management, welder, welding superior	Business manager, sales employee, warehouse employee	Head of quality management, employees of quality control

3.2 Interview instruments

The instruments applied in the VR-based expert interviews comprise a semi-structured interview guideline as well as two accompanying instruments (theory-based competence inventory, usability questionnaire). The interview guideline contains three interview modules. The first two modules form our VR-based PCM approach. The third module focuses on evaluating employees’ user acceptance of the applied VR-tool (Fig. 1). In the first interview module, job analysis is carried out using structured interview questions (e.g., “What exactly do you do at the (digitalized) process steps?”; “How may your work activities change compared to the actual process?”; “Which special challenges or job demands may arise here?”). In this context, the work activities to be conducted at the single future process steps as well as the relating job demands are systematically recorded.

In the second interview module, future competence requirements are identified with regard to single process steps (e.g., “Which competences are particularly important for carrying out the considered process step?”; “Which of these competences will become more important in the new process than before?”). The required competence (sub-) dimensions are selected from the theory-based competence inventory and stored at the relating process step in VR. The competence inventory has already been piloted in a conventional interview setting (cf., Depenbusch et al. 2021). It contains the four job-related dimensions of professional, methodological, social, and personal competence. In addition, it encompasses the digital competence as fifth dimension (Table 2). The competence (sub-) dimensions of the competence inventory were derived from the CRI (Kauffeld 2021), the competence atlas (Heyse and Erpenbeck 2009; Heyse 2010) and the Dig Comp 2.1 (Carretero et al. 2017).

Table 2 Excerpt from the theory-based competence inventory developed in Depenbusch et al. (2021)
Tab. 2 Ausschnitt aus dem theoriebasierten Kompetenzinventar, welches in Depenbusch et al. (2021) entwickelt wurde

Competence dimensions and relating sub-dimensions	Theory-based description
Professional competence	
Application of expertise	Practical application of job-specific and organization-related factual knowledge (e.g., Heyse 2010)
Application of interdisciplinary knowledge	Practical application of interdisciplinary knowledge (e.g., Heyse 2010)
Methodological competence	
Problem-solving	Recognizing deviations from the normal workflow and deriving creative solutions (e.g., Heyse 2010; Kauffeld 2021)
Holistic thinking	Considering a work process as a whole and recognizing causal relationships (e.g., Heyse 2010; Kauffeld 2021)
Social competence	
Communication	Communicating relevant information comprehensively and listening actively to the interlocutor (e.g., Heyse 2010)
Information dissemination and -processing	Obtaining and passing on relevant information (e.g., Ballod 2005)
Personal competence	
Ability to learn	Learning with high self-motivation and the willingness to constantly develop (e.g., Heyse 2010)
Assuming responsibility	Mindful working and compliance with organizational guidelines or rules (e.g., Heyse 2010)
Digital competence	
Digital content creation	Developing new digital content and complementing existing digital content (e.g., Carretero et al. 2017)
Information and data literacy	Browsing, searching, and filtering digital content as well as evaluating digital content (e.g., Carretero et al. 2017)

After identifying and mapping the relevant competences to the single future process steps, the required competence levels are determined. For this purpose, a predefined rating key (based on Decius and Schaper 2017) is used providing five different competence levels (Table 3).

In the third interview module, user acceptance and usability of the applied VR-tool are investigated. For this purpose, structured interview questions and a usability questionnaire are used. The interview questions refer to theory-based acceptance criteria of virtual technologies (specifically obtained from Brunkow and Hub 2018). At the same time, they are formulated in an open manner to simultaneously provide the possibility of exploring further acceptance-driving criteria. The content asked for refers to advantages and disadvantages of the virtual process visualization (3D-BPMN), the created feelings of immersion and presence, the possibilities of interaction, as well as the intuitiveness of the VR-tool (e.g., "Do you think it is easier to describe future work activities and related competence requirements using paper-based or VR-based process visualizations? What are the reasons for your opinion?"; "What strengths and weaknesses do you think exist in relation to paper-based and VR-based process visualizations?"; "Could the VR-tool be used intuitively?"; "Do you have any suggestions for improving the VR-tool?"). The usability questionnaire is formulated on the basis of ISO 9241-11 and ISO 9241-110 (Table 4). In order to realize adequate interview duration and to avoid overwhelming the employees by asking for too many fine-grained sub-criteria, we focus on usability criteria that are specifically important for our approach. The employees' extent of approval with the different usability criteria is assessed on a five-point Likert scale ranging from 1 = I strongly disagree to 5 = I strongly agree.

3.3 The VR-tool

The VR-tool used in the expert interviews maps the work environments of the three SMEs as virtual boxes. The single

Table 3 Rating key for determining the competence levels required with respect to the future and the existing business process (based on Decius and Schaper 2017)
Tab. 3 Einstufungsschlüssel zur Einschätzung der im zukünftigen und im bestehenden Geschäftsprozess erforderlichen Kompetenzniveaus (in Anlehnung an Decius und Schaper 2017)

Level	Description
0	No knowledge/no mastery required (with respect to the existing process)
1	Basic knowledge/basic mastery required (with respect to the existing process)
2	Advanced knowledge/reliable mastery required (with respect to the existing process) in standard work situations
3	Detailed knowledge/reliable mastery required (with respect to the existing process) in work situations that partially deviate from the normal workflow
4	Very detailed knowledge/reliable mastery required (with respect to the existing process) in totally new work situations

On the one hand, the rating key is used to rate the competence levels that are required from the employee in the future work process. Therefore, the term "required" is used. On the other hand, the rating key is also used to rate the actual competence of the employee (in order to subsequently identify future development needs). For this purpose, the term "with respect to the existing process" is added in parenthesis

Table 4 Excerpt from the usability questionnaire (based on ISO 9241-11 and ISO 9241-110) that has been applied in the expert interviews
Tab. 4 Ausschnitt aus dem im Rahmen der Expert:inneninterviews angewendeten Usability-Fragebogens (basierend auf ISO 9241-11 und ISO 9241-110) (übersetzt aus dem Deutschen)

	I strongly agree	I agree	I partly agree	I disagree	I strongly disagree
Effectiveness					
I had difficulties to answer the interview questions using the VR-tool	○	○	○	○	○
I was able to answer the interview questions completely using the VR-tool	○	○	○	○	○
Efficiency					
The cost-benefit ratio of using the VR-tool for answering the interview questions was appropriate	○	○	○	○	○
Satisfaction					
I think I will use the VR-tool on a regular basis	○	○	○	○	○
Overall, I am satisfied with the structure and functionalities of the VR-tool	○	○	○	○	○
Task appropriateness					
The functionalities of the VR-tool are appropriate for answering the interview questions	○	○	○	○	○
Self-descriptiveness					
It was always obvious to me which functionalities of the VR-tool I had to use to answer the interview questions	○	○	○	○	○
It was always obvious to me how to operate with the VR-tool to answer the interview questions	○	○	○	○	○
Conformity with user expectations					
The design of the VR-tool was comparable to other software I am familiar with	○	○	○	○	○
Fault tolerance					
I was able to manage incorrect entries with minimal effort for correction	○	○	○	○	○

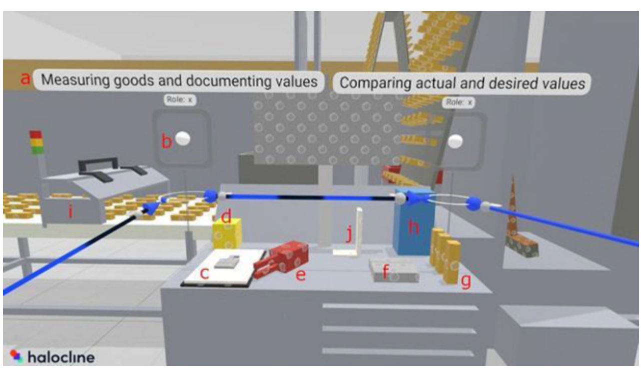

Fig. 2 Virtual representation of two process steps of the quality control process in SME 3. *a* Title of the process step, *b* virtual process node, *c* digital tablet, *d* box comprising labels, *e* label marker, *f* scales, *g* waffles, *h* glove box, *i* bakery production line, *j* protractor
Abb. 2 Virtuelle Darstellung zweier Prozessschritte des Qualitätssicherungsprozesses in KMU 3. *a* Titel des Prozessschritts, *b* virtueller Prozessnode, *c* digitales Tablet, *d* Etiketten-Box, *e* Etikettiergerät, *f* Waage, *g* Waffeln, *h* Handschuh-Box, *i* Produktionslinie, *j* Winkelmesser

steps of the future business- or work processes have been placed and linked within the virtual world using the established notation BPMN. The employees perceive their work environment and processes via a first-person perspective, thus allowing them to naturally experience future working scenarios (Fig. 2).

The work environments can be navigated using the point and teleport technique. According to this technique, a person points on a desired location with a VR-controller and is beamed to this location afterwards (Bozgeyikli et al. 2016). The competence inventory and rating key have been visualized through adding a tree-like interface logic within the virtual process nodes that represent the single process steps. The five competence dimensions (professional, methodological, social, personal and digital competence) and relating sub-dimensions are directly selectable by pointing and clicking with the VR-controller. When selecting a specific competence dimension, the relating sub-dimensions as well as the different levels of the rating key appear on a sub-level (Fig. 3).

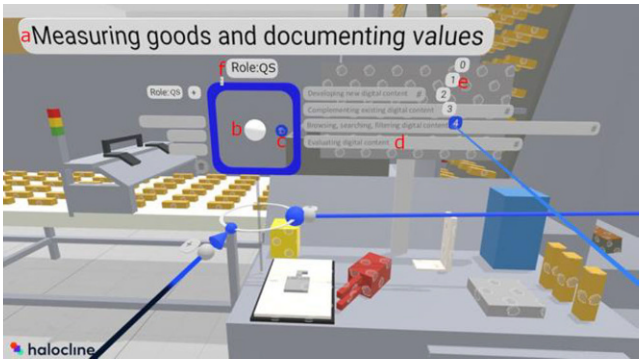

Fig. 3 The competence inventory and the rating key are anchored at a process step of the quality control process of SME 3, using a tree-like interface logic. When selecting a competence dimension, the relating competence sub-dimensions as well as the different levels of the rating key appear on a sub-level. *a* Title of the process step, *b* virtual process node, *c* field for selecting the competence dimension (e.g. digital competence dimension), *d* competence sub-dimensions (e.g. sub-dimensions of digital competence dimension), *e* levels of the rating key, *f* role of the employee who conducts the process step considered (e.g., QS = employee of quality control)

Abb. 3 Das Kompetenzinventar und der Einstufungsschlüssel werden über eine hierarchische Logik an einem Prozessschritt des Qualitätssicherungsprozesses von KMU 3 verankert. Wenn eine Kompetenzdimension ausgewählt wird, erscheinen die zugehörigen Kompetenz-Subdimensionen sowie die verschiedenen Kompetenzausprägungsgrade des Einstufungsschlüssels auf einer Unterebene. *a* Titel des Prozessschritts, *b* virtueller Prozessnode, *c* Auswahl der Kompetenzdimension (z. B. digitale Kompetenz), *d* Kompetenz-Subdimensionen (z. B. Subdimensionen der digitalen Kompetenz), *e* Einstufungsschlüssel, *f* Rolle des/der Mitarbeitenden, der/die den Prozessschritt ausführt (z. B. QS = Qualitätskontrolle)

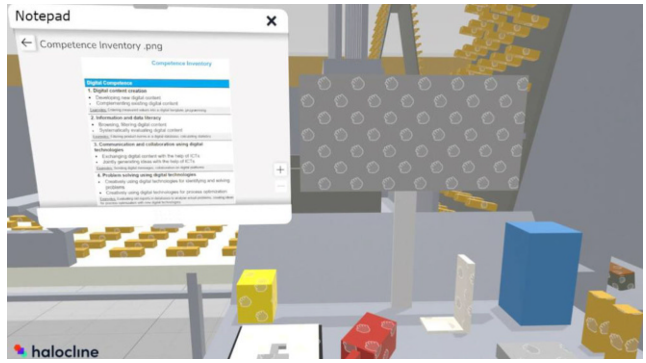

Fig. 4 Virtual notepad presenting an excerpt from the competence inventory in the virtual work environment of SME 3

Abb. 4 Virtuelles Notepad, welches in der virtuellen Arbeitsumgebung von KMU 3 eingeblendet wird und einen Auszug aus dem Kompetenzinventar zeigt

3.4 Procedure

The VR-based expert interviews lasted about 45 min and were audio-recorded for subsequent content analysis. Before starting with the interviews, the employees received a VR-training to practice teleporting through the virtual environment and selecting competences and competence levels from the competence inventory and rating key. The first two interview modules form our PCM approach and were carried out in VR. The third interview module served to derive and evaluate criteria of user acceptance and was conducted outside of VR. In the first interview module, employees were instructed to teleport to the single future process steps and explain the work activities they are going to carry out there. It was also asked for possible changes that the digitalization project may evoke with regard to their work activities and relating demands. To further underline their statements and explanations, employees were asked to give examples from day-to-day business. In the second interview module, the competence inventory and rating key were at first explained to the employees using the virtual notepad (Fig. 4). This way, they could simultaneously see the content that was explained to them. The employees were instructed to choose the competences that will be mostly required for successfully performing their future work activities from the virtual competence inventory. Afterwards, they selected the required competence levels from the virtual rating key. Again, they established their assignments using examples from day-to-day business.

In the third interview module, the employees were asked to discuss possible advantages and disadvantages of the applied VR-tool in terms of supporting our PCM approach. In particular, they were instructed to describe those attributes of the VR-tool that were most supportive. They were also asked to comment on the intuitiveness of the VR-tool and to derive suggestions for further improvement. Afterwards, the aim and content of the usability-questionnaire as well as the rating scale to be used for assessing the different usability criteria were explained to the employees. Finally, they filled out the usability questionnaire (paper-pencil).

3.5 Analysis

The VR-based expert interviews were transcribed and content analysed (Kuckartz 2018) using the software MAXQDA 12. Content analysis was carried out focusing on two analysis aims. The first aim was to derive job-specific competence facets in order to specify the competence models created in VR. The second aim was to derive and evaluate user acceptance criteria in order to identify VR-attributes that are particularly supportive for participatory PCM. The usability questionnaires have been evaluated descriptively using the software SPSS 28.

3.5.1 Analysis with regard to competence modeling

In order to derive job-specific competence facets, relevant interview text passages were allocated into a theory-based, deductive category system (Table 5). The categories repre-

Table 5 Category system for deriving job-specific competence facets
Tab. 5 Kategoriensystem zur Herleitung tätigkeitsspezifischer Kompetenzfacetten

Category	
C1 Professional competence	
C1.1	Application of expertise
C1.2	Application of manual skills
C1.3	Application of interdisciplinary knowledge
C1.4	Application of practical experience
C2 Methodological competence	
C2.1	Problem-solving
C2.2	Holistic thinking
C2.3	Reflection
C2.4	Planning capability
C2.5	Information dissemination and -processing
C3 Social competence	
C3.1	Teamwork and cooperation
C3.2	Communication
C3.3	Flexibility
C3.4	Positioning one's own point of view
C4 Personal competence	
C4.1	Willingness to work
C4.2	Resilience
C4.3	Ability to learn
C4.4	Assuming responsibility
C5 Digital competence	
C5.1	Digital content creation
C5.2	Information and data literacy
C5.3	Communication and collaboration using digital technologies
C5.4	Problem-solving using digital technologies

The competence categories of the category system reflect the competence dimensions and sub-dimensions of the theory-based competence inventory developed in Depenbusch et al. (2021)

sent the competence (sub-) dimensions listed in the competence inventory (see Chap. 3.2, Table 2). Thus, the upper level of the category system comprises the dimensions of professional, methodological, social, personal and digital competence. The second level summarizes the relating sub-dimensions obtained from the CRI (Kauffeld 2021), the competence atlas (Heyse and Erpenbeck 2009; Heyse 2010), and the Dig Comp 2.1 (Carretero et al. 2017). After structuring the interview material using the deductive competence categories, the inductive approach was applied to further differentiate the competences with job-specific content. In order to guarantee that the interview text passages could be classified clearly into the category system, the interrater-reliability has been assessed by calculating Cohen's kappa coefficient (Cohen 1960). Cohen's kappa indicates the extent to which two raters independently classify the same objects (it our case, these are the interview passages) into the same categories (in our case, these are the different competence (sub-) dimensions) (e.g., Brennan and Prediger 1981). For calculation, a random sample comprising 25% of all mapped interview text passages (N = 149 analysis units) has been used. Results indicate a kappa value of 0.882 for the first level of the category system and a kappa value of 0.856 for its second level.

3.5.2 Analysis with regard to user acceptance

In order to derive and evaluate the VR-specific acceptance criteria, relevant interview text passages were first allocated into a theory-based, deductive category system (Table 6). The main categories (e.g., virtual visualization, intuitiveness) were formulated on the basis of the interview questions of the third interview module and supplemented with further theory-based categories from literature (e.g., immersion, interaction) (e.g., Brunkow and Hub 2018). After structuring the interview material using the deductive competence categories, the inductive approach was applied to specify the categories with further sub-categories (e.g., the main category "interaction" has been inductively differentiated with the sub-categories "documentation and selection of competence requirements from the competence inventory" as well as "orientation and locomotion in the virtual work environment"). For calculating Cohen's kappa, a random sample of 25% of all mapped interview text passages was used (N = 78 analysis units). Results indicate a kappa value of 0.772 for the first level of the category system

Table 6 Category system for deriving and evaluating the acceptance criteria of the VR-tool
Tab. 6 Kategoriensystem zur Herleitung und Evaluierung der Akzeptanzkriterien des VR-tools

Category	
C1 Virtual visualization	
C1.1	In-situ visualization of work processes
C1.2	Infinite visualization of work processes
C2 Immersion and presence	
C3 Motivation and enthusiasm	
C4 Interaction	
C4.1	Selection and documentation of competence requirements
C4.2	Orientation and locomotion in the virtual environment
C5 Intuitiveness and learnability	
C6 Ergonomics and comfort	
C6.1	Physical strain when wearing the HMD and/or using the VR-controller
C6.2	Usage environment
C7 Customizability	
C7.1	Size adjustment of texts or changing the position of virtual objects
C7.2	Options for hiding and filtering information
C8 Quality of information	
C9 Trust	

Table 7 Example for creating the job-specific competence model for the employees of quality control in SME 3
Tab. 7 Beispiel für die Herleitung des tätigkeitsspezifischen Kompetenzmodells für die Mitarbeitenden der Qualitätskontrolle in KMU 3

Competence dimensions and relating sub-dimensions	Exemplary interview text passages (translated from German)	Job-specific competence facets
Professional competence		
Application of manual skills	"Yes, I will take a couple of waffles and measure them. I check the weight, length and diameter. I also check whether the appearance of the product fits."	Measuring the product (e.g., length, diameter, weight) and conducting visual inspections
Personal competence		
Assuming responsibility	"You also have to be able to decide quickly and you have also to be ready to decide whether a product can still be processed."	Responsible decision-making with regard to product quality

and a kappa value of 0.826 for its second level. The usability questionnaires (filled out by the employees as part of the third interview module) were analyzed descriptively using the software SPSS 28. For each usability criteria that is listed in the questionnaire, its mean value and standard deviation were calculated.

3.6 Developing job-specific competence models

After content analysis, job-specific competence facets have been formulated on the basis of the interview text passages that have been mapped to the different competence categories. The resulting job-specific competence facets were summarized to job-specific competence models. The job-specific competence models serve to further differentiate and finalize the prospective and process-related competence models. Table 7 shows an example of how job-specific competence facets for the employees of quality control in SME 3 have been formulated.

3.7 Developing prospective and process-related competence models

In order to develop the final prospective and process-related competence models, a three-step methodology was applied (Fig. 5). In a first step, the competences that have been identified and mapped by the employees to the single process steps during the VR-interviews were transferred to text-based templates. In this way, preliminary versions of the prospective and process-related competence models have been created. In a second step, the job-specific competence facets (that have been derived after content analysis) were added to the related competence (sub-) dimensions. In a third step, the final prospective and process-related competence models were validated by a direct supervisor concerning their correctness and completeness. Afterwards, the actual competence levels of the employees were also added by the ir supervisor. For this purpose, the same rating key has been used that was also applied during the VR-based expert interviews.

4 Results

4.1 Results of VR-based PCM

The central results of our VR-based PCM approach are the prospective and process-related competence models. In order to create these competence models, job-specific competence facets were first formulated and summarized in respective job-specific competence models. The job-specific competence facets were integrated afterwards into the preliminary versions of the prospective and process-related competence models (created by the employees during

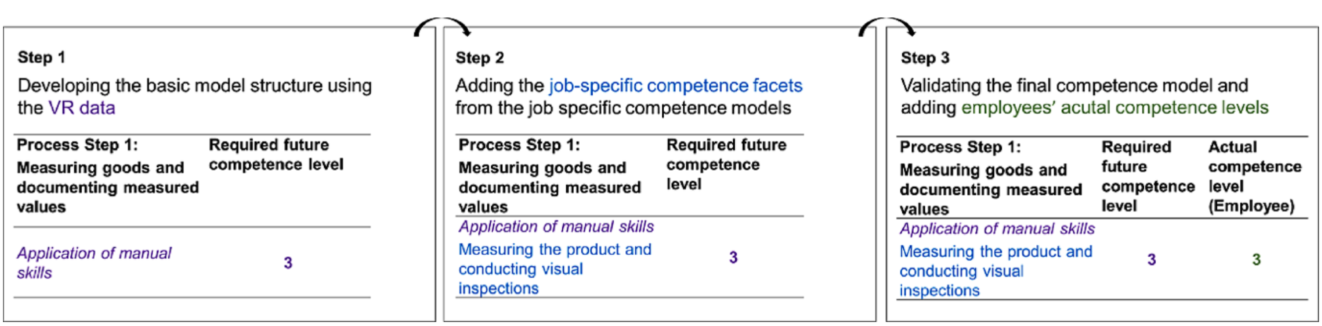

Fig. 5 Process of creating a prospective and process-related competence model for the employees of quality control in SME 3
Abb. 5 Prozess zur Erstellung eines prospektiven und prozessbezogenen Kompetenzmodells für die Mitarbeitenden der Qualitätssicherung in KMU 3

the VR-based expert interviews) in order to differentiate the competence (sub-) dimensions listed therein. This way, prospective and process-related competence models have been created for those groups of employees, whose jobs will be part of the SMEs' future digitalized business processes. The jobs or groups of employees considered in SME 1 are the project management, the welders, the employees of quality control and the employees in logistics (N = 4 jobs/groups of employees). The jobs or groups of employees considered in SME 2 are the purchasers, the sales employees, the warehouse employees, and the employees in shipping management (N = 4 jobs/groups of employees). The jobs or groups of employees considered in SME 3 are the employees of quality control, the machine operators and the technicians (N = 3 jobs/groups of employees). In the following, Chap. 4.1.1 first shows excerpts from the job-specific competence models for one selected job/group of employees for each SME. Afterwards, Chap. 4.1.2 presents excerpts from the corresponding prospective and process-related competence models.

4.1.1 Job-specific competence models

Tables 8, 9 and 10 show excerpts from the job-specific competence models for the welders in SME 1, the warheouse employees in SME 2, and the employees of quality control in SME 3. The work activities of these jobs/groups of employees will change the most in the course of digitalization. For each required future competence dimension (professional, methodological, social, personal and digital competence), the corresponding sub-dimension and the relating job-specific competence facet are exemplarily listed. Considering, e.g., the professional competence dimension, manual skills will still be required in each of the above-mentioned jobs. In SME 1, the welders need to be able to manually re-weld the first samples when these do not

Table 8 Excerpt from the job-specific competence model for the welders in SME 1
Tab. 8 Ausschnitt aus dem tätigkeitsspezifischen Kompetenzmodell für die Schweißfachkräfte in SME 1

Competence dimensions and sub-dimensions	Job-specific competence facets
Professional competence	
Application of manual skills	Manually re-welding the first samples
Methodological competence	
Problem-solving	Informing the project management about possible causes of faults and jointly deriving adequate solutions
Social competence	
Positioning one's own point of view	Positioning one's own point of view when discussing the execution of a new customer order with the project management
Personal competence	
Assuming responsibility	Careful and precise checking of the welding device using the correct checklist stored in the digital tablet
Digital competence	
Problem-solving using digital technologies	Identifying causes of faults in the welding device using the error histories stored in the digital tablet

Table 9 Excerpt from the job-specific competence model for the warehouse employees in SME 2
Tab. 9 Ausschnitt aus dem tätigkeitsspezifischen Kompetenzmodell für die Lagerist:innen in SME 2

Competence dimensions and sub-dimensions	Job-specific competence facets
Professional competence	
Application of manual skills	Correct operation of the hand scanner
Methodological competence	
Planning capability	Appropriate time and task management
Social competence	
Positioning one's own point of view	Communicating with customers when short-term changes in delivery cannot be met
Personal competence	
Assuming responsibility	Careful storage of new goods
Digital competence	
Information and data literacy	Filtering, researching and interpreting the data needed for shipment planning (e.g., planned incoming and outgoing goods)

Table 10 Excerpt from the job-specific competence model for the employees of quality control in SME 3
Tab. 10 Ausschnitt aus dem tätigkeitsspezifischen Kompetenzmodell für die Mitarbeitenden der Qualitätssicherung in SME 3

Competence dimensions and sub-dimensions	Job-specific competence facets
Professional competence	
Application of manual skills	Controlling product characteristics (e.g., length, diameter, weight) and conducting visual inspections
Methodological competence	
Problem-solving	Analyzing causes of problems (e.g., machine faults) and communicating them to the technician
Social competence	
Positioning one's own point of view	Informing machine operators when their products do not meet quality standards
Personal competence	
Assuming responsibility	Responsible decision-making with regard to product quality standards
Digital competence	
Digital content creation	Entering measured values of the product characteristics into the digital tablet

meet the required product standards. In SME 2, the warehouse employees should be able to correctly operate the hand scanner in order to digitalize product information and to transfer them to the inventory management system. In SME 3, the employees of quality control need to be able to control product characteristics and to conduct visual inspections. Considering, e.g., the social competence dimension, the skill of positioning one's own point of view will be required in all three SMEs. In SME 1, the welders are required to position their own point of view when new customer orders are discussed with the project management. In SME 2, the warehouse employees should be able to adequately communicate with customers when short-term delivery requests cannot be met. In SME 3, the employees of quality control are required to inform the machine operators when the products do not meet the quality standards. Considering the digital competence dimension, the welders in SME 1 should be able to solve problems using digital technology. In particular, this relates to the ability of identifying causes of machine faults by looking up error histories in a digital tablet. In SME 2, information and data literacy will be required of the warehouse employees in terms of filtering, researching, and interpreting digital data for shipment planning. In SME 3, the employees of quality control should be able to create digital content, such as entering measured product values into a digital tablet.

4.1.2 Prospective and process-related competence models

The job-specific competence facets described in Chap. 4.1.1 were integrated into the preliminary versions of the prospective and process-related competence models (created by the employees during the VR-based expert interviews) in order to differentiate the competence (sub-) dimensions listed therein. This way, final versions of prospective and process-related competence models have been created for the jobs/groups of employees that will be part of the SMEs' future business processes. The prospective and process-related competence models thus present which competences will be required at the individual future process steps of these jobs/groups of employees. Tables 11, 12 and 13 show excerpts from the final prospective and process-related competence models for the welders in SME 1, the warehouse employees in SME 2, and the employees of quality control in SME 3. For the process steps listed in these competence models, the relating future required competence (sub-) dimensions, the corresponding job-specific competence facets, as well as the required competence levels are presented. Additionally, the actual competence levels of three randomly selected employees for each SME are included. The employees' actual competence levels have been determined by their direct supervisor. In general, the prospective and process-related competence models can be used to derive future development needs of individual employees or to identify future competence requirements for particular jobs/groups of employees.

4.1.3 Future development needs of individual employees

Considering, e.g., the digital competence dimension, future development needs will arise in all three SMEs. Considering SME 1, this will be the case for the competence sub-dimension "problem-solving using digital technologies". This competence sub-dimension is required at process step 1

Table 11 Excerpt from the prospective and process-related competence model for the welders in SME 1
Tab. 11 Auszug aus dem prospektiven und prozessbezogenen Kompetenzmodell der Schweißfachkräfte in SME 1

Process Step 1: **Checking the welding device**	Required future competence level	Employee 1 (actual competence level)	Employee 2 (actual competence level)	Employee 3 (actual competence level)
Assuming responsibility:				
Careful and precise checking of the welding device using the correct checklist stored in the digital tablet	**4**	**3**	**4**	**1**
Problem-solving using digital technologies:				
Identifying causes of faults in the welding device using error histories stored in the digital tablet	**4**	**1**	**2**	**1**
Process Step 2: **Reporting defects of the welding device to the project manager**	Required competence level	Employee 1 (actual competence level)	Employee 2 (actual competence level)	Employee 3 (actual competence level)
Communication using digital technologies:				
Reporting the faults found in the welding device to the project management	**2**	**3**	**4**	**4**
Problem-solving:				
Informing the project management about possible causes of faults and jointly deriving adequate solutions	**2**	**3**	**3**	**1**

"checking the welding device". While there is required a competence level of 4 (reliable mastery in totally new work situations), employee 2 only has a competence level of 2 (reliable mastery in standard work situations). For employees 1 and 3, the competence gap is even larger as they only have a competence level of 1 (basic mastery). In consequence, all three employees should be trained in filtering and interpreting error histories stored in a digital tablet in order to quickly identify faults in the welding device. In view of the competence sub-dimension "communication using digital technologies", which is required at process step 2 "reporting faults of the welding device to the project manager", no future development needs arise. All three employees meet the required competence level or are even overqualified (Table 11).

With regard to SME 2, future development needs will occur for all three employees at process step 1 "reporting information about the glass products to the inventory management system". This applies the competence sub-dimension "digital content creation". Thus, a respective training should enable the employees to scan product labels using a hand scanner and to manually type product information into the inventory management system. Considering process step 2 "shipment planning using the inventory management system", there will also arise development needs for all three employees. This specifically concerns the competence sub-

Table 12 Excerpt from the prospective and process-related competence model for the warehouse employees in SME 2
Tab. 12 Auszug aus dem prospektiven und prozessbezogenen Kompetenzmodell der Lagerist:innen in SME 2

Process Step 1: Reporting information about the glass products to the inventory management system	Required future competence level	Employee 1 (actual competence level)	Employee 2 (actual competence level)	Employee 3 (actual competence level)
Application of manual skills:				
Correct operation of the hand scanner	**1**	**1**	**1**	**1**
Digital content creation:				
Scanning the labels of product boxes and entering relevant product information into the inventory management system	**3**	**2**	**2**	**1**
Process Step 2: Shipment planning using the inventory management system	Required competence level	Employee 1 (actual competence level)	Employee 2 (actual competence level)	Employee 3 (actual competence level)
Planning capability:				
Appropriate time and task management	**4**	**3**	**2**	**1**
Information and data literacy:				
Filtering, researching and interpreting the data needed for shipment planning (e.g., planned incoming and outgoing goods)	**3**	**2**	**2**	**1**

Table 13 Excerpt from the prospective and process-related competence model for the employees of quality control in SME 3
Tab. 13 Auszug aus dem prospektiven und prozessbezogenen Kompetenzmodell der Mitarbeitenden der Qualitätssicherung in KMU 3

Process Step 1: Controlling and documenting product characteristics	Required future competence level	Employee 1 (actual competence level)	Employee 2 (actual competence level)	Employee 3 (actual competence level)
Application of manual skills:				
Controlling product characteristics (e.g., length, diameter) and conducting visual inspections	**3**	**4**	**3**	**3**
Digital content creation:				
Entering measured values of the product characteristics into the digital tablet	**4**	**3**	**3**	**2**
Process Step 2: Comparing actual and desired values	Required competence level	Employee 1 (actual competence level)	Employee 2 (actual competence level)	Employee 3 (actual competence level)
Assuming responsibility:				
Responsible decision-making with regard to product quality standards	**4**	**4**	**4**	**4**
Problem-solving:				
Analysing causes of problems (e.g., machine faults) and communicating them to the technician	**4**	**4**	**3**	**4**

dimension "information and data literacy". Thus, employees should be trained in searching, filtering and interpreting digital data which are needed for shipment planning (e.g., planned incoming and outgoing goods) (Table 12).

In SME 3, future development needs will occur for all three employees concerning the competence sub-dimension "digital content creation". This competence sub-dimension is required at process step 1 "controlling and documenting product characteristics". Against this background, a training should be planned that enables the employees of quality control to enter the product characteristics they have measured (e.g., length, weight) into a digital tablet (Table 13).

4.1.4 Future competence requirements of particular jobs/groups of employees

The prospective and process-related competence models can also be used to identify future competence requirements of particular jobs/groups of employees. This study focuses on the group of employees whose jobs will be part of the SMEs' future digitalized business processes. Again, in SME 1, this is the case for the project management, the welders, the employees of quality control, and the employees in logistics (N = 4 jobs/groups of employees). In SME 2, this concerns the purchasers, the sales employees, the warehouse employees, and the employees in shipping management (N = 4 jobs/groups of employees). In SME 3, this is the case for the employees of quality control, the machine operators and the technicians (N = 3 jobs/groups of employees). The future competence requirements of these groups of employees can be determined by calculating competence frequency distributions. In this context, the prospective and process-related competence models are used to count how often the various competence (sub-) dimensions are required for the considered jobs/groups of employees. The underlying assumption is that the competence (sub-) dimensions that are particularly frequently required will become the most important and thus need to be trained (cf., Yang et al. 2006). This study presents the frequency distributions of the different competence sub-dimensions at SME-level. In this context, it was first counted for each above-mentioned job per SME, how often the different competence sub-dimensions are listed in their prospective and process-related competence models. Afterwards, the resulting

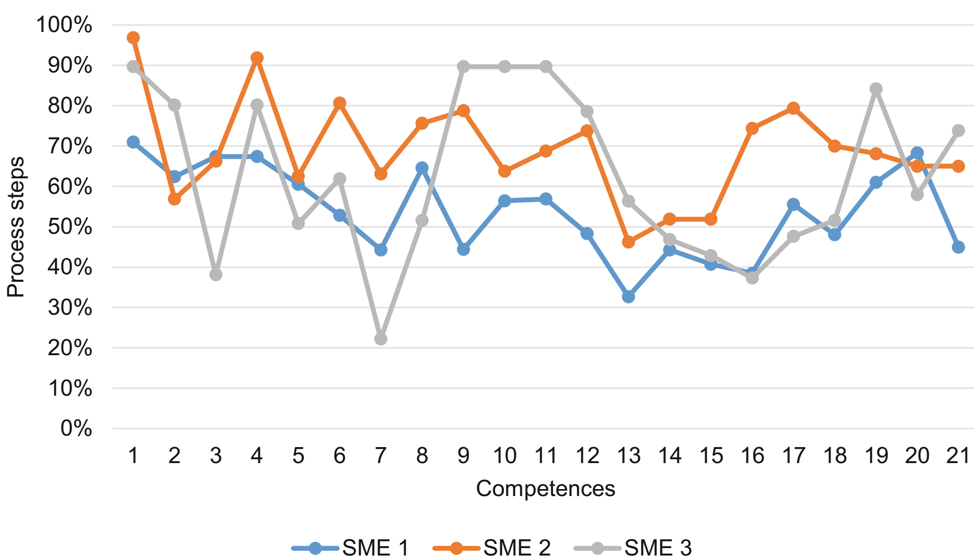

Fig. 6 Frequency distribution of the competences required in the future digitalized businesses processes in the three SMEs. The 21 competences listed on the x-axis represent the competence sub-dimensions listed in the competence inventory. These competence sub-dimensions are also mapped in the prospective and process-related competence models. *1* application of expertise, *2* application of manual skills, *3* application of interdisciplinary knowledge, *4* application of practical experience, *5* problem-solving, *6* holistic thinking, *7* reflection, *8* planning capability, *9* information dissemination and -processing, *10* teamwork and cooperation, *11* communication, *12* flexibility, *13* positioning one's own point of view, *14* willingness to work, *15* resilience, *16* ability to learn, *17* assuming responsibility, *18* digital content creation, *19* information and data literacy, *20* communication and collaboration using digital technologies, *21* problem-solving using digital technologies

Abb. 6 Häufigkeitsverteilung der Kompetenzen, die in den zukünftig digitalisierten Geschäftsprozessen der drei KMU gefordert werden. Die an der x-Achse aufgeführten 21 Kompetenzen repräsentieren die im Kompetenzinventar aufgeführten Kompetenz-Subdimensionen. Diese Kompetenz-Subdimensionen sind ebenfalls in den prospektiven und prozessbezogenen Kompetenzmodellen aufgeführt. *1* Anwendung von Fachwissen, *2* Anwendung von Fertigkeiten, *3* Anwendung von fachübergreifendem Wissen, *4* Anwendung von Erfahrungswissen, *5* Problemlösefähigkeit, *6* Ganzheitliches Denken, *7* Reflexion, *8* Planungsfähigkeit, *9* Informationsweitergabe und -verarbeitung, *10* Teamfähigkeit und Zusammenarbeit, *11* Kommunikationsfähigkeit, *12* Flexibilität, *13* Positionieren des eigenen Standpunktes, *14* Einsatzbereitschaft, *15* Belastbarkeit, *16* Lernfähigkeit, *17* Verantwortungsfähigkeit, *18* Erzeugen digitaler Daten, *19* Umgang mit digitalen Daten, *20* Digitale Kommunikation und Zusammenarbeit, *21* Problemlösen mittels digitaler Technologien sums of the competence sub-dimensions were divided by the number of process steps these jobs/groups of employees will conduct in the SME's future business process. The resulting mean values per job/group of employees were then summed up and divided by the total number of the jobs/groups of employees considered in the respective SME. The resulting competence frequency distributions for each SME are displayed in Fig. 6.

In view of the professional competence dimension, the sub-dimensions "application of expertise" and "application of experience" will become particularly important in all three SMEs. The relevance of these sub-dimensions becomes visible by the high frequency with which they will be required in the SMEs' future business processes. For example, "application of expertise" will be required in approx. 70% of all considered future process steps in SME 1, in approx. 97% of all considered future process steps in SME 2, and in approx. 90% of all considered future process steps in SME 3. The competence sub-dimension "application of experience" will be required in approx. 67% of all considered future process steps in SME 1, in approx. 91% of all considered future process steps in SME 2, and in approx. 80% of all considered future process steps in SME 3. Against this background, it becomes clear that the newly digitalized working steps still afford high expertise and experience that should be prospectively trained. Focusing on the methodological competence dimension, the sub-dimension "planning capability" will become specifically important in SME 1 and SME 2. In consequence, employees should be trained to conduct adequate time and task management. In SME 1, the competence sub-dimension "problem-solving" will additionally become relevant. Thus, the error histories stored in the digital tablets seem not to take over every kind of problem analysis. In consequence, the employees still need to be able to detect faults using their technical knowledge and thus should be trained accordingly. In SME 2

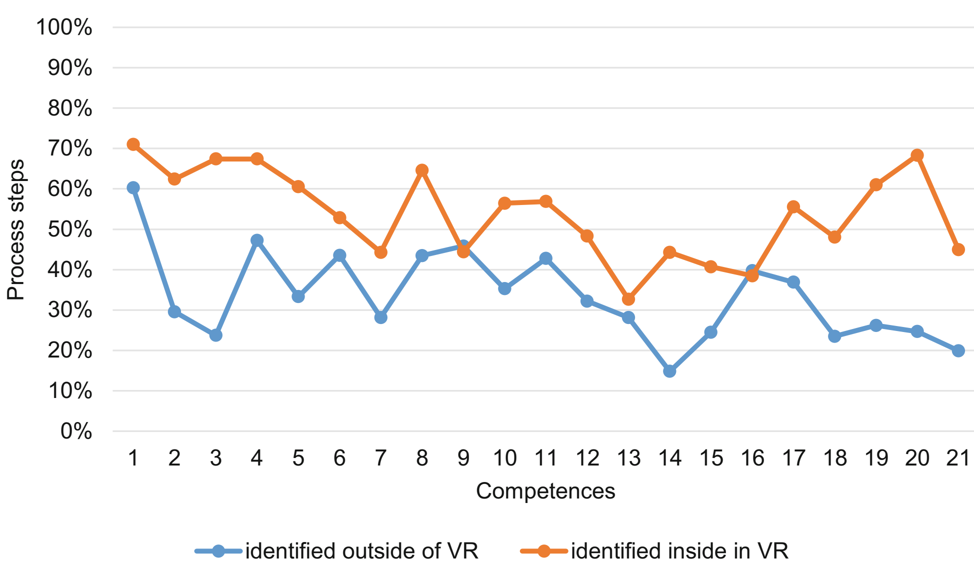

Fig. 7 Frequency distributions of the competences required in the future digitalized businesses process of SME 1. The upper frequency distribution was determined on the basis of the competence models created in VR. The lower frequency distribution was determined on the basis of the competence models created outside of VR (cf., Depenbusch et al. 2021). The 21 competences listed on the x-axis represent the competence sub-dimensions listed in the competence inventory. These competence sub-dimensions are also included in the prospective and process-related competence models. *1* application of expertise, *2* application of manual skills, *3* application of interdisciplinary knowledge, *4* application of practical experience, *5* problem-solving, *6* holistic thinking, *7* reflection, *8* planning capability, *9* information dissemination and -processing, *10* teamwork and cooperation, *11* communication, *12* flexibility, *13* positioning one's own point of view, *14* willingness to work, *15* resilience, *16* ability to learn, *17* assuming responsibility, *18* digital content creation, *19* information and data literacy, *20* communication and collaboration using digital technologies, *21* problem-solving using digital technologies

Abb. 7 Häufigkeitsverteilung der im zukünftig digitalisierten Geschäftsprozess von KMU 1 geforderten Kompetenzen. Die obere Häufigkeitsverteilung wurde auf Grundlage der in der VR entwickelten Kompetenzmodelle bestimmt. Die untere Häufigkeitsverteilung wurde auf Grundlage der außerhalb der VR entwickelten Kompetenzmodelle (vgl. Depenbusch et al. 2021) hergeleitet. Die an der x-Achse aufgeführten 21 Kompetenzen repräsentieren die im Kompetenzinventar aufgeführten Kompetenz-Subdimensionen. Diese Kompetenz-Subdimensionen sind ebenfalls in den prospektiven und prozessbezogenen Kompetenzmodellen aufgeführt. *1* Anwendung von Fachwissen, *2* Anwendung von Fertigkeiten, *3* Anwendung von fachübergreifendem Wissen, *4* Anwendung von Erfahrungswissen, *5* Problemlösefähigkeit, *6* Ganzheitliches Denken, *7* Reflexion, *8* Planungsfähigkeit, *9* Informationsweitergabe und -verarbeitung, *10* Teamfähigkeit und Zusammenarbeit, *11* Kommunikationsfähigkeit, *12* Flexibilität, *13* Positionieren des eigenen Standpunktes, *14* Einsatzbereitschaft, *15* Belastbarkeit, *16* Lernfähigkeit, *17* Verantwortungsfähigkeit, *18* Erzeugen digitaler Daten, *19* Umgang mit digitalen Daten, *20* Digitale Kommunikation und Zusammenarbeit, *21* Problemlösen mittels digitaler Technologien and 3, the competence sub-dimensions "holistic thinking" as well as "information dissemination and -processing" will become additionally relevant. In consequence, employees should be trained to adapt a holistic view on the work in the digitalized business process instead of narrowly focusing on their own tasks. Considering the social competence dimension, the future focus seems to be placed on "teamwork and cooperation" in SME 1 and on "flexibility" in SME 2. In SME 3, "teamwork and cooperation" and "flexibility" as well as "communication" will become important. Thus, the digital technologies that will be implemented in the SMEs (digital tables, inventory management system) won't undermine social interaction, but rather seem to encourage it. With regard to the personal competence dimension, the sub-dimension "assuming responsibility" will become quite important in all three SMEs and thus still needs to be trained. In view of the digital competence dimension, the sub-dimension "information and digital data literacy" will become important in all three SMEs. SME 1 places a further focus on the sub-dimension "communication and collaboration using digital technologies". In SME 2, this is the case for "digital content creation" and in SME 3 for "problem-solving using digital technologies". In consequence, the various sub-dimensions of digital competence should be continuously trained to prepare employees adequately for their future digital work.

4.2 Potential advantages of VR for conducting participatory PCM

In order to outline whether VR actually provides advantages for participatory PCM, the competence models obtained during the VR-based expert interviews (VR-condition) are compared with the competence models that emerged from the conventional approach presented in Depenbusch et al. (2021) (non-VR-condition). To find out ‚which VR-at-

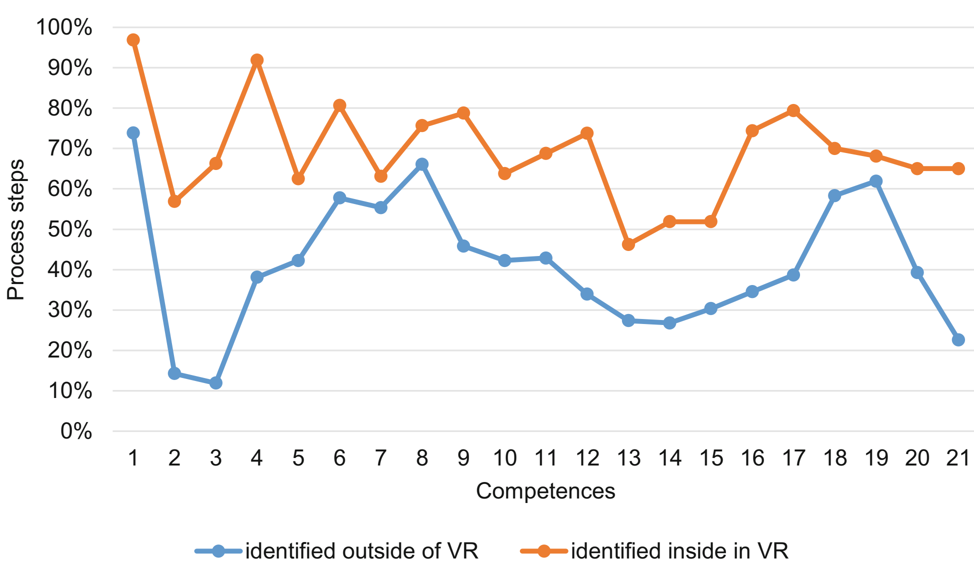

Fig. 8 Frequency distributions of the competences required in the future digitalized businesses process of SME 2. The upper frequency distribution was determined on the basis of the competence models created in VR. The lower frequency distribution was determined on the basis of the competence models created outside of VR (cf. Depenbusch et al. 2021). The 21 competences listed on the x-axis represent the competence sub-dimensions listed in the competence inventory. These competence sub-dimensions are also included in the prospective and process-related competence models. *1* application of expertise, *2* application of manual skills, *3* application of interdisciplinary knowledge, *4* application of practical experience, *5* problem-solving, *6* holistic thinking, *7* reflection, *8* planning capability, *9* information dissemination and -processing, *10* teamwork and cooperation, *11* communication, *12* flexibility, *13* positioning one's own point of view, *14* willingness to work, *15* resilience, *16* ability to learn, *17* assuming responsibility, *18* digital content creation, *19* information and data literacy, *20* communication and collaboration using digital technologies, *21* problem-solving using digital technologies

Abb. 8 Häufigkeitsverteilung der im zukünftig digitalisierten Geschäftsprozess von KMU 2 geforderten Kompetenzen. Die obere Häufigkeitsverteilung wurde auf Grundlage der in der VR entwickelten Kompetenzmodelle bestimmt. Die untere Häufigkeitsverteilung wurde auf Grundlage der außerhalb der VR entwickelten Kompetenzmodelle (vgl. Depenbusch et al. 2021) hergeleitet. Die an der x-Achse aufgeführten 21 Kompetenzen repräsentieren die im Kompetenzinventar aufgeführten Kompetenz-Subdimensionen. Diese Kompetenz-Subdimensionen sind ebenfalls in den prospektiven und prozessbezogenen Kompetenzmodellen aufgeführt. *1* Anwendung von Fachwissen, *2* Anwendung von Fertigkeiten, *3* Anwendung von fachübergreifendem Wissen, *4* Anwendung von Erfahrungswissen, *5* Problemlösefähigkeit, *6* Ganzheitliches Denken, *7* Reflexion, *8* Planungsfähigkeit, *9* Informationsweitergabe und -verarbeitung, *10* Teamfähigkeit und Zusammenarbeit, *11* Kommunikationsfähigkeit, *12* Flexibilität, *13* Positionieren des eigenen Standpunktes, *14* Einsatzbereitschaft, *15* Belastbarkeit, *16* Lernfähigkeit, *17* Verantwortungsfähigkeit, *18* Erzeugen digitaler Daten, *19* Umgang mit digitalen Daten, *20* Digitale Kommunikation und Zusammenarbeit, *21* Problemlösen mittels digitaler Technologien tributes may be specifically advantageous, user acceptance evaluation has been carried out. In this context, standardized usability criteria as well as VR-specific acceptance criteria have been considered. In the following, Chap. 4.2.1 presents the results gained from the comparative analysis of the prospective and process-related competence models. Chapter 4.2.1 outlines the results of user acceptance evaluation and presents concrete advantages of VR for conducting participatory PCM.

4.2.1 Comparing competence requirements identified using VR-based and non-VR-based PCM approaches

When comparing the level of detail of the prospective and process-related competence models developed in the VR-condition with those created in the non-VR-condition, it becomes obvious whether there are differences regarding the future competence requirements that have been derived inside in VR and outside of VR. For comparison, we contrasted the competence frequency distributions obtained from the prospective and process-related competence models derived in the VR-condition with the competence frequency distributions resulting from the prospective and process-related competence models developed in the non-VR-condition. The "VR-based competence frequency distributions" have already been calculated and presented in Chap. 4.1.4. The "non-VR-based competence frequency distributions" have been calculated in the same way. The jobs/groups of employees considered in Depenbusch et al. (2021) were the same as those considered in our study. Figures 7, 8 and 9 compare the VR-based and the non-VR-based frequency distributions of each SME. In general, it becomes obvious that more competence requirements have been identified and mapped to the single process steps in the VR-condition than it was the case in the non-VR-condition. This becomes visible by the fact that the VR-based frequency distributions of the three SMEs lie mostly above the non-VR-based frequency distributions. Considering, e.g.,

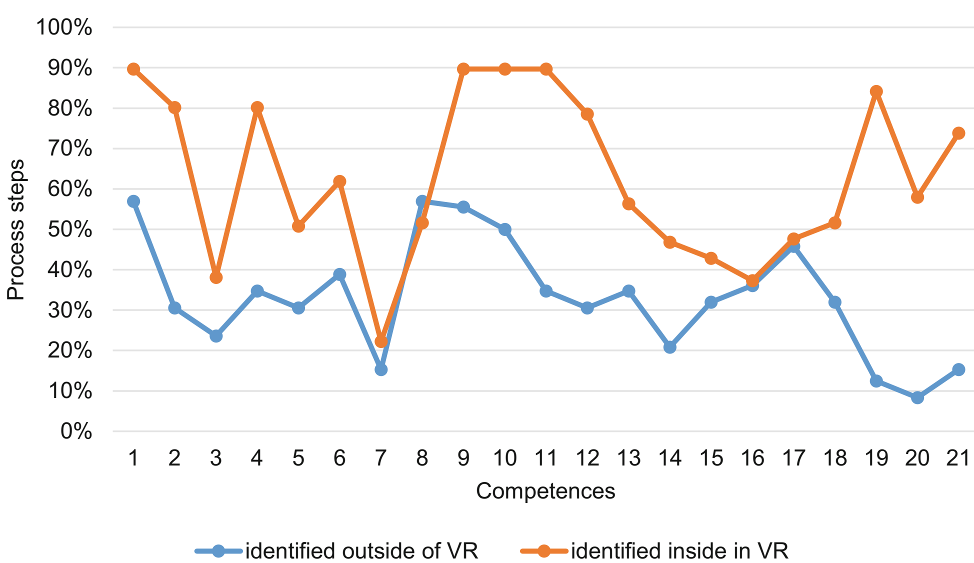

Fig. 9 Frequency distributions of the competences required in the future digitalized businesses process of SME 3. The upper frequency distribution was determined on the basis of the competence models created in VR. The lower frequency distribution was determined on the basis of the competence models created outside of VR (cf., Depenbusch et al. 2021). The 21 competences listed on the x-axis represent the competence sub-dimensions listed in the competence inventory. These competence sub-dimensions are also included in the prospective and process-related competence models. *1* application of expertise, *2* application of manual skills, *3* application of interdisciplinary knowledge, *4* application of practical experience, *5* problem-solving, *6* holistic thinking, *7* reflection, *8* planning capability, *9* information dissemination and -processing, *10* teamwork and cooperation, *11* communication, *12* flexibility, *13* positioning one's own point of view, *14* willingness to work, *15* resilience, *16* ability to learn, *17* assuming responsibility, *18* digital content creation, *19* information and data literacy, *20* communication and collaboration using digital technologies, *21* problem-solving using digital technologies

Abb. 9 Häufigkeitsverteilung der im zukünftig digitalisierten Geschäftsprozess von KMU 3 geforderten Kompetenzen. Die obere Häufigkeitsverteilung wurde auf Grundlage der in der VR entwickelten Kompetenzmodelle bestimmt. Die untere Häufigkeitsverteilung wurde auf Grundlage der außerhalb der VR entwickelten Kompetenzmodelle (cf., Depenbusch et al. 2021) hergeleitet. Die an der x-Achse aufgeführten 21 Kompetenzen repräsentieren die im Kompetenzinventar aufgeführten Kompetenz-Subdimensionen. Diese Kompetenz-Subdimensionen sind ebenfalls in den prospektiven und prozessbezogenen Kompetenzmodellen aufgeführt. *1* Anwendung von Fachwissen, *2* Anwendung von Fertigkeiten, *3* Anwendung von fachübergreifendem Wissen, *4* Anwendung von Erfahrungswissen, *5* Problemlösefähigkeit, *6* Ganzheitliches Denken, *7* Reflexion, *8* Planungsfähigkeit, *9* Informationsweitergabe und -verarbeitung, *10* Teamfähigkeit und Zusammenarbeit, *11* Kommunikationsfähigkeit, *12* Flexibilität, *13* Positionieren des eigenen Standpunktes, *14* Einsatzbereitschaft, *15* Belastbarkeit, *16* Lernfähigkeit, *17* Verantwortungsfähigkeit, *18* Erzeugen digitaler Daten, *19* Umgang mit digitalen Daten, *20* Digitale Kommunikation und Zusammenarbeit, *21* Problemlösen mittels digitaler Technologien

Table 14 Mean and standard deviation of the usability criteria (based on ISO 9241-11 and ISO 9241-110)
Tab. 14 Mittelwerte und Standardabweichungen der Usability-Kriterien (basierend auf ISO 9241-11 und ISO 9241-110)

Usability criteria	Item	Mean	SD
ISO 9241-11 (Performance measures)			
Effectiveness	I had difficulties to answer the interview questions using the VR-tool	4.0*	1.1
	I was able to answer the interview questions completely using the VR-tool	3.7	1.3
Efficiency	The cost-benefit ratio of using the VR-tool for answering the interview questions was appropriate	3.7	1.2
Satisfaction	I think I will use the VR-tool on a regular basis	3.4	1.4
	Overall, I am satisfied with the structure and functionalities of the VR-tool	4.1	1.4
ISO 9241-110 (Dialogue Principles)			
Task appropriateness	The functionalities of the VR-tool are appropriate for answering the interview questions	4.0	0.7
Self-descriptiveness	It was always obvious to me which functionalities of the VR-tool I had to use to answer the interview questions	4.0	1.0
	It was always obvious to me how to operate with the VR-tool to answer the interview questions	4.0	1.1
Conformity with user expectations	The design of the VR-tool was comparable to other software I am familiar with	3.3	1.2
Fault tolerance	I was able to manage incorrect entries with minimal effort for correction	4.0	1.0

The five-point Likert scale ranges from 1 = I strongly disagree to 5 = I strongly agree; * = recoded; N = 9

the professional competence dimension, the biggest differences between the VR-based and non-VR-based frequency distributions can be identified concerning the competence sub-dimension "application of manual skills". This is the case for all three SMEs. In the VR-condition, "application of manual skills" has been identified to become relevant in approx. 62% of all considered future process steps in SME 1, in approx. 57% of all considered future process steps in SME 2, and in approx. 80% of all considered future process steps in SME 3. In the non-VR-condition, the percentage values are much smaller. Here, "application of manual skills" has been identified to become relevant in approx. 29% of all considered future process steps in SME 1, in approx. 14% of all considered future process steps in SME 2, and in approx. 30% of all considered future process steps in SME 3. These differences can possibly be explained by the fact that VR functioned as a facilitator for identifying and documenting future competence requirements with regard to single process steps. This way, employees were enabled to continuously maintain a prospective and process-related focus of analysis. In consequence, future required competences have been identified more comprehensively and concretely in VR. Slight differences in the competence frequency distributions (VR vs. non-VR) can also be found with regard to the social and digital competence dimensions. Considering the social competence dimension, in SME 2 and 3 this specifically concerns the sub-dimensions "teamwork and cooperation" as well as "communication". In SME 1, this is the case for the sub-dimension "positioning of one's own point of view". Thus, VR seemed to support employees in understanding the interconnectedness and complexity of the future business processes. This way, it was easier for them to recognize future situations in which collaboration will be required. Focusing on the digital competence dimension, large frequency differences could be identified in SME 1 concerning all related sub-dimensions. In SME 2 and SME 3, this is specifically the case for "communication and collaboration using VR" as well as "problem-solving using VR". Thus, VR additionally supported employees in recognizing and understanding the future use of the new technology (Fig. 9).

4.2.2 User acceptance evaluation

As already mentioned, we conducted a user acceptance evaluation in order to identify concrete VR-attributes that are specifically advantageous for participatory PCM. For this purpose, both standardized usability criteria as well as VR-specific acceptance criteria have been analyzed. In the following, the usability results are first presented. In this case, a quantitative evaluation of the usability questionnaires has been conducted. Afterwards, the results of the VR-specific acceptance criteria are presented. These have been derived and evaluated qualitatively.

Usability criteria The usability questionnaires were analysed descriptively using the software SPSS 28. Table 14 summarizes the mean values and standard deviations for each usability criteria listed in the questionnaire. Generally speaking, the usability criteria evaluate whether the VR-tool could be used ergonomically in terms of conducting our participatory PCM approach. Overall, the usability scores underline that the VR-tool enabled and supported the employees to adequately carry out the PCM approach

Table 15 Acceptance criteria that have been derived and evaluated qualitatively
Tab. 15 Akzeptanzkriterien, die inhaltsanalytisch hergleitet und evaluiert wurden

Acceptance criteria	Context-related description
Virtual visualization	The VR-tool creates virtual visualizations close to reality (e.g., Wiendahl et al. 2003). Future work environments and processes of the SMEs are realistically visualized, e.g., through providing 3D and infinite in-situ visualizations
Immersion and presence	The VR-tool creates virtual visualizations that lead to feelings of immersion and presence (e.g., Jensen and Konradsen 2018). Employees should be supported to dive into their future work processes and environments, thus leading to natural or intuitive experiences and behaviors
Motivation and enthusiasm	The VR-tool increases user motivation and enthusiasm (e.g., Carrion et al. 2021; Janzik 2022). Employees should enjoy interacting with the VR-tool and thus conducting the PCM approach (e.g., in terms of describing future work activities and identifying respective competence requirements)
Interaction	The VR-tool offers adequate possibilities for interaction (e.g., Wiendahl et al. 2003). On the one hand, these comprise ergonomic functionalities to move around and orientate well in the virtual work environment or in the virtual work processes. On the other hand, these comprise ergonomic functionalities to select competence requirements from the competence inventory and to document them at virtual process steps
Trust	The VR-tool provides functionalities that decrease employees' initial skepticism and uncertainty about using VR (e.g., Brunkow and Hub 2018). These relate, e.g., to the functionality that incorrect competence assignments can be corrected with little effort. A further functionality would be that targeted process steps can be found quickly—even after accidently moving in the wrong direction before
Ergonomics and comfort	The HMD and VR-controllers can be used in a comfortable manner and with low physical strain (e.g., Brunkow and Hub 2018). An adequate wearing comfort of the HMD is guaranteed and the VR-controllers can also be used comfortably
Intuitiveness and learnability	The VR-tool can be used intuitively. Its operating concept can be easily learned and memorized by the employees (e.g., Brunkow and Hub 2018). Employees should intuitively and quickly learn to use the VR-controller to teleport in the VR-environment and to select competence requirements from the competence inventory
Customizability	The VR-tool provides appropriate possibilities to adapt the presented information or interaction options to one's own needs (e.g., Brunkow and Hub 2018; Kähler et al. 2019). Employees should be able to adjust the size of text or to change the position of virtual process steps in order to get a better look at them
Quality of information	The content portrayed by the VR-tool is relevant and comprehensible (e.g., Brunkow and Hub 2018). On the one hand, the virtual work environment and process steps provide all relevant information needed for PCM. On the other hand, the competence inventory comprises all competences that are relevant for the employees in their future work processes

(e.g., teleporting to the different process steps in order to describe them, selecting required future competences from the competence inventory).

The employees gave highest average approval concerning their satisfaction with the structure and functionalities of the VR-tool (mean = 4.1). This is reflected in the almost equally pronounced dialog principles of task appropriateness, self-descriptiveness and fault tolerance (each with a mean of 4.0). Satisfactory values of approval are also achieved with regard to the perceived effectiveness (mean = 4.0; mean = 3.7) and efficiency of the VR-tool (mean = 3.7). Lowest approval is given to the conformity of the VR-tool with user expectations (mean = 3.3) and their intention to use the VR-tool on a regular basis (mean = 3.4). Standard deviations vary between 0.7 and 1.4, indicating that the employees' responses deviate most with regard to their perceived satisfaction (standard deviation = 1.4) and less concerning their perceived task appropriateness of the VR-tool (standard deviation = 0.7).

Acceptance criteria The VR-attributes that became specifically advantageous for the participatory PCM approach are presented in Table 15. In the following, these attributes will be explained more in detail by citing concrete interview statements as well as referring to relating experience made during the pilot runs in the three SMEs.

During the VR-based expert interviews, it soon became evident that the virtual visualization of the future business processes promotes employees' business process understanding. Specifically, the in-situ process visualization was described as helpful for adequately explaining future work activities and deriving relating competence requirements: "I actually think it is better that the work activities in VR are located directly at the workplace so that you can think about the process more easily" (sales employee, SME 2). It could also be observed that the employees were highly immersed in their future work process and it felt to them as if they were actually there: "You are in your totally own world. That's incredible" (employee of quality control, SME 3). This way, high levels of motivation and enthusiasm have been achieved: "It is just more interesting, keeps you awake and encourages you to be active" (employee of quality control, SME 3).

Also, the functionalities for interaction provided by the VR-tool were truly supportive for our PCM approach. On the one hand, these relate to the teleport function, which has been used in the expert interviews to give in-situ descriptions of future work activities. On the other hand, these comprise the functionalities offered to select and document competence requirements. In our case, the competence inventory was anchored at every virtual process node using a tree-like interface logic. Employees underlined, that this made it easier for them to punctually concentrate on a specific competence dimension: "I have a filter and can concentrate on what I am working on […]" (business manager, SME 2). However, in terms of the quality of information portrayed, it was partly figured out that the scope and complexity of the competence inventory should be reduced: "Sometimes, it was difficult to interpret the level of detail in the competence inventory with regard to process steps that are rather banal in practice" (business manager, SME 2). In addition, employees stated that entering explanations to clearly define the identified competence requirements was truly time-consuming when applying the "VR-keyboard". Thus, they suggested adding audio-memo-boxes at each process step. Another attribute that was identified as supportive to conduct PCM refers to the high ergonomics and comfort of the VR-tool. It was indicated that the HMD provided an adequate wearing comfort. In addition, it could be observed that the VR-controller enabled to comfortably teleport across the virtual environment and to select competences from the competence inventory.

Further attributes that were identified as beneficial for our PCM approach refer to the high intuitiveness and learnability as well as customizability of the VR-tool. The majority of employees learned quickly to select competence dimensions from the competence inventory and to teleport across the virtual environment: "[…] when teleporting, your thumb has to be on the touchpad the whole time […]. But you notice that after a relatively short time" (head of quality management, SME 3). In consequence, the majority of employees quickly reduced their initial skepticism about using VR. Specifically, when experiencing that an accidental mistake (e.g., selecting the wrong competence requirement from the competence inventory) could be corrected with little effort, employees soon built up trust.

5 Discussion

This study contributes to the scientific discourse by demonstrating how VR can be used to carry out participatory PCM and by deriving concrete VR-attributes that are specifically advantageous in this context. It could be pointed out that a VR-tool mapping the SMEs' future work environments as virtual boxes and presenting their future business processes by means of a 3D-BPMN notation is suitable for our PCM approach. In particular, anchoring the PCM instruments (in our case, it relates to the competence inventory and the rating key) at the single process steps enabled employees to maintain a prospective and process-related analysis focus. Employees could easily select and document required future competence dimensions at individual virtual process steps. The resulting prospective and process-related competence models could be used to identify future competence development needs of individual employees as well as competence requirements of particular jobs/groups of employees. In accordance with previous literature (cf., Carretero et al. 2017; van Laar et al. 2017), results show that there specifically occur development needs in terms of the digital competence in all three SMEs (e.g., in terms of digital content creation, technology-based problem-solving). This can be related to the fact that digital technologies have been used rarely in the three SMEs before. The relevance of the above-mentioned digital competences is also reflected by the competence frequency distributions that have been derived using the prospective and process-related competence models created in the VR-based expert interviews. Further competences that could be outlined to become truly important in the three SMEs are "application of expertise", "application of practical experience", "holistic thinking", "information dissemination and -processing", "planning capability" and "assuming responsibility" (cf., Harteis 2018; van Laar et al. 2017, 2019). These findings may be related to the fact that the future business processes as well as the inherent information flows gain in complexity during digitalization (cf., Harteis 2018).

This study further outlines whether VR provides advantages over conventional methods in terms of conducting participatory PCM. For this purpose, the competence frequency distributions obtained from the prospective and process-related competence models derived using our VR-based PCM approach have been compared with the competence frequency distributions obtained from the prospective and process-related competence models derived using a conventional PCM approach (cf., Depenbusch et al. 2021). Results demonstrate that much more competence requirements have been identified and mapped to the single process steps using our VR-based approach than it was the case when using the conventional PCM approach. The underlying competence frequency distributions show that VR specifically supported a detailed identification of professional competence requirements (e.g., manual skills, practical experience), social competence requirements (e.g., teamwork and cooperation, communication), and digital competence requirements (e.g., information and data literacy, communication and collaboration using digital technologies). In view of the professional competence requirements, it could be said that VR seems to underline the still existing importance of practical skills. Otherwise, these are often perceived as implicit by the employees or even not recognized by persons other than the job holders who were commissioned to create respective competence models. In view of the social competence dimension, VR seems to support employees in understanding the complexity of future business processes and thus to recognize future situations that require collaboration and social interaction. Considering the digital competence dimension, VR seems to help employees understand when and how to use the new digital technology.

Against this background, concrete VR-attributes have been derived that might be specifically beneficial for participatory PCM. For this purpose, user acceptance evaluation was carried out using standardized usability criteria as well as VR-specific acceptance criteria. Considering the usability criteria, it turned out that the employees were particularly satisfied with the structure and functionalities of the VR-tool. It could be further revealed that the VR-tool fulfilled satisfactory degrees of task appropriateness, self-descriptiveness and fault tolerance. Nevertheless, employees' approval of intending to use the VR-tool on a regular basis was comparatively small. Although employees quickly built up trust towards using VR, there seems to remain a barrier with regard to its regular use. In consequence, VR should be applied more regularly in the organizational context, e.g., in the context of employee workshops (cf., Müller et al. 2022). The VR-specific acceptance criteria provide further arguments in favor of using VR for participatory PCM. These specifically underline that VR is a facilitator for including employees as competence modelers. It turned out that the in-situ visualization of the future business process steps (using 3D-BPMN notation) increased employees' business process understanding (cf., Oberhauser et al. 2018; Oberhauser and Pogolski 2019) and thus their ability to derive respective competence requirements. Further advantageous VR-attributes identified are, e.g., the interaction functionalities of the VR-tool, such as the teleport function, or the possibility of selecting and documenting competence requirements with regard to single process steps. This way, a prospective and process-related analysis focus could be maintained during the expert interviews. Finally, VR provided a high motivational potential and increased employees' enthusiasm to conduct PCM, thus activating them to concretely and comprehensively identify important competence requirements.

In sum, the current state of research on competence modeling (cf., Hegmanns et al. 2019; Robinson et al. 2007; Yang et al. 2006) is expanded with a further approach that not only combines the prospective and process-related analysis perspective, but also uses VR as a tool to involve employees' expertise. Thus, the demand to derive future competence requirements with respect to the company-specific scenario of digitalization (cf., Ganz et al. 2019; Harteis 2018) is being met. This way, we also expand the current state of research on VR-based methods of competence development and assessment (cf., Akdere et al. 2021; Hickman and Akdere 2018; Jensen et al. 2017; Paszkiewicz et al. 2021). Instead of focusing on the measurement and development of competences that individuals actually need, our approach starts one step before by focusing on the identification of future competence requirements. This way, companies are able to train their employees already before the new competence requirements come into practice.

The presented VR-approach takes various quality criteria into account. Objectivity, referring to the extent to which results are free from bias (Ali and Yusof 2011; Guba and Lincoln 1994), is guaranteed by applying (semi-)standardised interview instruments (e.g., interview guideline, competence inventory). The interview questions can be supplemented with open questions to gain more information about, e.g., job-specific competence facets. Although the use of open questions may reduce objectivity, it also supports a more comprehensive competence modeling (Kato-Beiderwieden et al. 2021). Reliability, describing the extent to which findings can be replicated (Ali and Yusof 2011), is also considered. To ensure that the interview text passages can be classified clearly into the two category systems used and developed in our study, interrater reliability was determined. According to Altman (1991), the resulting Cohen's kappa values indicate that both raters classified the interview text passages with an almost perfect approval into the category system encompassing the different competence categories and with a good approval into the category system summarizing the acceptance-determining evaluation criteria. Finally, the criterion of validity, indicating how accurately a certain issue is measured by an instrument (Brown 1996, 2000), is addressed. To guarantee valid competence modeling, both deductive and inductive approaches are combined, thus allowing determining future competence requirements comprehensively and from different perspectives of analysis.

6 Limitations

Since our VR-based PCM approach has been piloted in SMEs, its applicability to large companies is restricted. Moreover, the sample size needs to be increased to strengthen the insights found in the pilot runs. Another limitation is that the results highly depend on employees' ability to work with the VR-tool. Specifically, employees with less experience in using digital technologies needed more time to learn dealing with the VR-tool. Consequently, it was sometimes challenging to obtain enough information for subsequently deriving job-specific competence facets. Therefore, a special focus should be placed on those process steps and requirements that change most in the course of digitalization. A further limitation is that the reliability of the competence assignments and ratings could not be determined in our study and should therefore be evaluated in future work. Finally, the results of the user acceptance evaluation cannot be generalized since they relate to our specific approach and VR-tool. However, the results indicate promising advantages of VR to facilitate participatory approaches of competence modeling.

7 Implications

7.1 Implications for science

This study contributes to scientific research by investigating how PCM can be conducted using VR and by deriving VR-attributes that are beneficial to include employees as competence modelers. It could be revealed that the applied VR-tool generally fulfils theory-based and VR-specific acceptance criteria as well as the standardized usability criteria listed in ISO 9241-11 and 9241-110. Therefore, the presented VR-approach serves as a fruitful basis for the creation of further approaches in the context of VR-based competence management. Moreover, future research could explore additional acceptance criteria by using, for example, a larger sample and/or different evaluation methods (e.g., cognitive walkthroughs).

7.2 Implications for practice

Our VR-approach enables organizations to include employees' expertise when developing prospective and process-related competence models. This way, a realistic picture of future competence requirements and development needs can be derived, thus providing an important prerequisite for remaining competitive in the era of digitalization. Immersive VR-technology functions as an enabler for employee participation by making future work processes more experienceable and thus mobilizing employees' tacit process- and task-related knowledge. In addition, VR makes it possible to include multiple perspectives (e.g. employee & direct supervisor) on a concrete analysis level in competence modeling approaches.

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