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Digital learning for old(er) workers: A systematic review of age-appropriate vocational education and training

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ABSTRACT

Demographic change and digitalization are reshaping both the workforce and the nature of work itself, highlighting the need for age-appropriate continuing vocational education and training (CVET). This systematic review examines the current state of research on digital CVET tailored specifically for old(er) workers. Guided by an adapted framework based on Lewin’s Change Theory (1947), we conceptualized digital learning as a three-phase process and aligned our research questions with each phase: *RQ1 (prelude)* explores factors influencing motivation and attitude shifts; *RQ2 (engagement)* examines the adoption of new learning behaviors and necessary adjustments in delivery; and *RQ3 (sustain)* investigates strategies to support long-term knowledge retention. We systematically searched four databases and one search engine (ERIC, GeroLit, PubMed, FIS Bildung, Google Scholar), identifying 40 relevant publications/studies (2001–2023). Inclusion criteria were: (i) publications in English or German; (ii) journal articles, book chapters, reports, or conference papers; (iii) investigation of digital learning measures; (iv) employed learners aged 40 or older; (v) job-related training; and (vi) detailed descriptions of learning elements. Dual-independent screening ensured rigor. Findings reveal a fragmented evidence base with inconsistent terminology, but highlight key factors shaping digital CVET experiences across all phases: stereotypes, self-efficacy, motivation, prior experiences, organizational support, learning format, and historical/cultural context. Practical implications include designing flexible, tailored learning environments, providing continuous practice and feedback, and fostering organizational conditions that reduce stereotypes and other barriers to participation. Future research should prioritize representative samples, longitudinal methods, and cross-cultural and sectoral perspectives to better meet the learning preferences of old(er) workers.

Introduction

Both the fast-developing digitalization and the demographic aging of workforces have a substantial impact on work processes and workforces. As a result of these megatrends “the workplace of the future will be different from today” (German Federal Ministry of Labour and Social Affairs [BMAS], 2017, p. 4). Companies will have to respond to changed requirements or entirely new competencies in increasingly digitized work environments, and do so simultaneously with a shrinking and aging workforce (Komp-Leukkunen et al., 2022; Naegele & Ertl, 2023). To keep old(er) workers’ (defined as at least 40 years old; see the section addressing the characteristics of the included publications for a more thorough

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discussion) skills up to date with ever-shortening innovation cycles, the necessity of continuing vocational education and training (CVET) is frequently emphasized (Slowey, 2008; UNESCO, 2020).

Digitalization not only affects the way people work but also how they learn. On the one hand, the importance of ‘digital literacy’ which Eshet-Alkalai (2004, p. 102) defines as a “system of skills and strategies used by learners and users in digital environments” is rising, leading to an increase in learning measures aimed at developing digital competencies. On the other hand, learning opportunities and settings are increasingly being moved into the digital space, an ongoing trend, which has been significantly intensified by the COVID-19 pandemic (De et al., 2020; König & Seifert, 2022; Pit et al., 2021; Schönfeld & Schürger, 2020) and the rise of artificial intelligence (Wilkens, 2020). Representative data from Germany show that more than 70% of companies have offered digital CVET, and more than 50% of these companies did so for the first time in 2020 (Schönfeld & Schürger, 2020). Digital learning environments are said to “[...] revolutionize traditional educational processes by radically changing models of knowledge acquisition, the role of teachers and trainers, as well as the institutional framework and methods of assessment” (Braun et al., 2020, p. 4).

It is important to recognize that the term ‘digital learning’ is often ambiguous and can encompass concepts such as ‘e-learning,’ ‘virtual learning,’ ‘digital learning platforms,’ or ‘learning videos.’ Additionally, there is a tendency to confuse ‘digital learning’ with ‘digital skills’ by overlooking the distinction between two key aspects: i) the ability to use digital tools and technologies (‘digital skills’); and ii) ‘digital learning,’ a term used to describe learning that happens through or with the help of digital technologies. Although learners need some digital skills to participate in digital learning, digital learning is not just about developing these skills. It can include a wide range of topics and learning processes beyond digital skills alone (Punie, 2007; Punie & Ala-Mutka, 2007).

In general, there is growing optimism and increasing political support for digital learning environments (Formosa, 2012a, 2012b). They are seen as a flexible, location-independent way to help small and medium-sized enterprises develop training programs more cost-effectively (European Centre for the Development of Vocational Training, 2022; Flake et al., 2019), as well as to reskill old(er) workers, extend careers, and prevent labor market exclusion (Hsu et al., 2013; Li et al., 2023).

However, initial studies on old(er) workers and digital CVET show that employers often view these formats as unsuitable for aging workforces (Schönfeld & Schürger, 2020). This may be related to the field of geragogy, which argues that learning preferences change over the life-course and that old(er) learners’ learning needs differ from those of young(er) adults, and might not be met in digital learning environments (Frerichs, 2010; Heenan, 2016; Urlick, 2017). While learning preferences describe how individuals prefer to acquire and process information, learning needs refer to specific gaps in (digital) knowledge or (digital) skills which may vary between generations. Furthermore, geragogy has shown that, in regard to old(er) learners, empowerment and autonomy, along with social learning and ‘learning in the process of work,’ are beneficial (Formosa, 2002; Gates & Wilson-Menzfeld, 2022).

Besides shortcomings in how learning environments are designed, biased ageist beliefs and doubts about older workers’ competencies or motivation to learn can lead supervisors to overlook those for digital training opportunities. This bias also cultivates self-doubt among old(er) individuals, leading to reluctant involvement in digital learning environments (Maurer et al., 2003; Wrenn & Maurer, 2004), particularly as old(er) workers are often perceived as less technologically savvy (Köttl et al., 2021; Wanka & Gallistl, 2018). Albeit these ageist stereotypes neglect intra-individual differences as well as biographical reasons for exposure to digital work and learning environments, they persist and might have been intensified amidst the COVID-19 pandemic (Ayalon et al., 2021; Naegele et al., 2018).

The growing significance of how old(er) workers integrate into digital learning environments underscores an emerging area for future consideration. Nevertheless, there is a lack of scientific evidence on the extent to which digital learning settings consider the specific needs and conditions of old(er) learners. This, combined with ageist perceptions, may even hinder the skill development of old(er) individuals (Naegele & Ertl, 2023).

In order to address this research gap, we have conducted the *first systematic review on age-appropriate digital CVET*. The aim was to identify the determinants of these environments that are

conductive or obstructive (obstacles and opportunities) to the specific learning needs of old(er) workers in order to reduce the risk of exclusion from digital learning environments.

As we conceptualize learning as a dynamic process of change (Aylward, 2012), we have developed a phase-based analytical framework by adapting and extending Kurt Lewin's three-stage Change Theory (1947). This framework divides the learning process into three distinct temporal phases—*prelude*, *engagement*, and *sustain*—each of which is addressed by one of the following research questions (for a more thorough discussion of the framework developed for this review, see the section addressing the synthesis).

RQ1. *What factors contribute to the engagement of old(er) workers in digital learning measures?*

RQ2. *What adjustments in the delivery of digital learning are necessary to meet the learning needs and preferences of old(er) workers, while facilitating the acquisition of new knowledge?*

RQ3. *How can the long-term integration of newly acquired knowledge by old(er) workers be supported to ensure sustainable anchoring?*

To address these research questions, we begin by explaining our applied methods. We then present the results, organizing them directly around the three core research questions. Finally, we conclude with a discussion of our findings and an evaluation of limitations, offering concrete recommendations for future research.

Methods

This study employs a systematic review methodology to comprehensively identify, appraise, and synthesize international evidence relevant to our defined research questions (Page et al., 2021). Systematic reviews utilize explicit, rigorous, and transparent methods designed to minimize bias and ensure reliable, reproducible findings that can inform practice, policy, and future research (Munn et al., 2018). In accordance with these principles, we adhered closely to the PRISMA 2020 guidelines (Page et al., 2021) throughout the review process. All methodological decisions including eligibility criteria, data extraction procedures, and synthesis methods were predetermined prior to screening and consistently applied throughout the review.

Given the multifaceted and evolving nature of the topic old(er) workers and digital learning—the systematic review approach enables us to critically assess the quality of included publications and to integrate diverse evidence to generate robust, evidence-based results. While alternative approaches such as scoping reviews (Arksey & O'Malley, 2005; Levac et al., 2010) may be suitable for broad mapping of literature, our focus on addressing specific research questions, performing formal quality assessments, and synthesizing findings aligns closely with established systematic review standards (Munn et al., 2018).

The following section outlines our research process. We begin by detailing the information sources and search strategy, followed by the eligibility criteria and selection process. Afterwards, we discuss our quality assessment and detail the data analysis, including the identification of relevant publications, extraction, and synthesis of relevant data to address the research questions. Finally, we present the characteristics of the included publications, offering an overview of the data corpus.

Information sources and search strategy

We selected search terms based on established scientific terminology to ensure a comprehensive literature search on digital learning for old(er) workers in CVET. The terms covered three components: the (i) digital component (e.g., 'digital,' 'e-learning,' 'computer-assisted,' and 'remote'), focusing on technology-supported learning, (ii) activity (e.g., 'CVET,' 'training,' 'lifelong learning,' and

‘vocational education and training’), reflecting structured education approaches, and (iii) target group (e.g., ‘older employees’ and ‘workers’), addressing aging professionals. Search strings combined terms from all three areas using logical operators (‘AND’ or ‘+’) (see Table A1 in the appendix).

We conducted the primary search across four relevant databases (ERIC, GeroLit, PubMed, and FIS Bildung), covering educational sciences, gerontology, and health sciences, with the search period completed in May 2023. We did not apply any filters during the search to ensure comprehensive results. In June 2025, we conducted an updated search that did not yield new inclusions.

Additionally, we carried out a supplementary search using a search engine, in line with Gusenbauer and Haddaway (2019). We conducted this Google Scholar search without applying any filters. It served as a key pathway for gray literature, which often contains recent and valuable findings (Hoffecker, 2021; Paez, 2017). As Lee et al. (2023) note, including gray literature is especially important when studying minoritized populations, who are frequently underrepresented in empirical research. Moreover, this approach ensures broad, multidisciplinary coverage (Martín-Martín et al., 2020).

For each search, we listed all hits from the databases and the first 100 results from the search engine to maintain relevance (Haddaway et al., 2015). This resulted in a total of 11,444 hits.

Eligibility criteria and selection process

To identify the most relevant texts for the review, these had to meet the following eligibility criteria:

- (i) Written in German or English
- (ii) Available as a journal article, book or book chapter, report or conference contribution
- (iii) Investigating at least one learning measure in digital space
- (iv) Learners are employed
- (v) Learning measure was job-related
- (vi) Learners are 40 years old or older
- (vii) The text provides further information and specific instructions regarding the configuration of the learning measure(s) addressed (e.g., regarding didactics, user interface, etc.)

At least two independent reviewers evaluated the publications and successively narrowed them down; title, abstract, and full-text screening were conducted independently (Figure 1). Any disagreements were resolved through discussion and input from an independent third reviewer. Publications that did not meet the defined eligibility criteria and/or failed the quality assessment were excluded. Additionally, we searched the references of the remaining publications for other relevant and eligible publications (snowball procedure), which produced 6 additional findings.

Quality assessment

For all publications retained after our eligibility assessment (Figure 1), we applied a three-point scale to assign an overall rating of low, medium, or high. To guide this rating, support consistency and transparency, we developed a concise 11-item checklist informed by established reporting and appraisal standards, including STROBE (Elm et al., 2008) for qualitative studies, PRISMA (Page et al., 2021) for systematic reviews, and COREQ (Tong et al., 2007) for quantitative studies. Each criterion was derived by identifying overlapping quality indicators across the three established standards and consolidating them into a single format applicable across methodological approaches. For example, aspects such as clarity of the research question (*item 2*), adequacy (*item 5*) and transparency of sampling (*item 6*), reporting of ethical considerations (*item 8*), clarity (*item 9*) and validity of findings (*item 10*) are emphasized in all three checklists and therefore formed the backbone of the tool (Table A2 in the appendix).

The assessment combined reviewer expertise with structured evaluation. For instance, missing basic sample information was rated negatively. Overall, the scoring approach allowed for structured

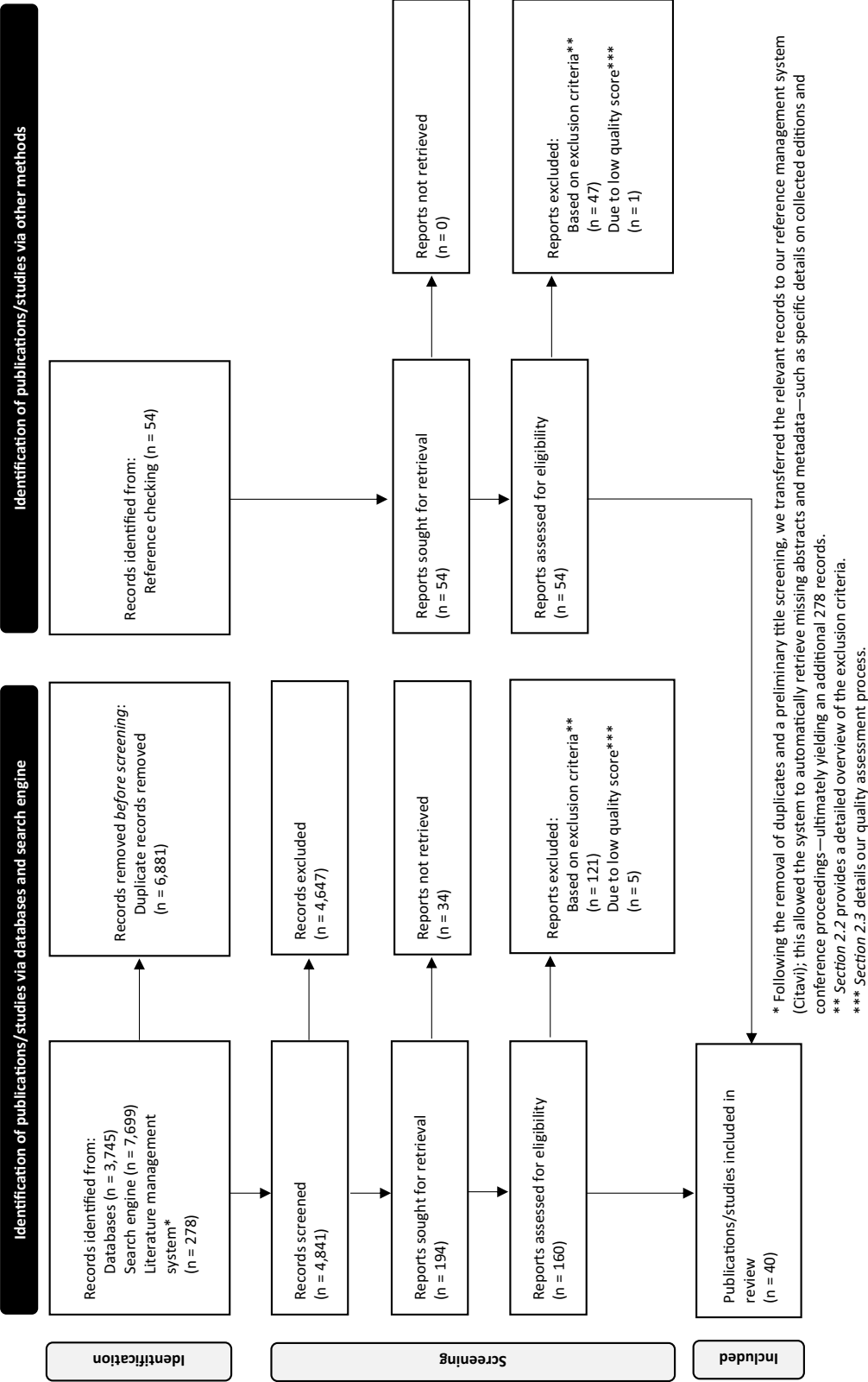


Figure 1. Flow diagram (based on Page et al., 2021).

yet flexible evaluation across heterogeneous publication types (Table A3 in the appendix). Publications that initially received a 'low' rating based on the aforementioned criteria were reassessed by a third independent reviewer. If the 'low' rating was confirmed, the publication was excluded from further analysis ($n = 6$).

Finally, we checked the interrater reliability via Cohen's Kappa ($k = \frac{p_o - p_e}{1 - p_e}$) (Cohen, 1960). Across all reduction steps, this resulted in a value of $= 0,55$, which indicates that the interrater reliability can be regarded as moderate, but perfectly acceptable (Greve & Wentura, 1997; Landis & Koch, 1977).

Ultimately, 40 publications/studies were included in the review (Figure 1).

Data analyses

Extraction

As part of the extraction process, we *first* identified key characteristics of each publication (e.g., bibliographical information, epistemological interest, study design, sample information, potential ageism, etc.; see Table 1 in the section addressing the characteristics of the included publications). *Secondly*, to examine the findings more closely, we coded the publications/studies using MAXQDA. One reviewer extracted data per publication; a random third of the publications/studies were double-coded by a second reviewer for verification.

The extracted data primarily consisted of factual information. As the process did not require subjective judgment, only minor discrepancies arose during verification. These were reviewed jointly and resolved through consensus. The high level of agreement indicates clear coding categories and a systematic, transparent approach that minimized error and supported methodological rigor.

Synthesis

We applied a *narrative synthesis procedure* (Popay et al., 2006; Snilstveit et al., 2012) to combine the previously extracted data and systematically analyze it: Among the various techniques available for *narrative synthesis* (Snilstveit et al., 2012), we first employed *aggregative synthesis techniques*—suitable for summarizing and generalizing descriptive evidence (Snilstveit et al., 2012). Our aim was to gain an overview of publications' characteristics (e.g., year, type, study design, sample size, etc.) and terminology ('older workers' and 'digital learning') used in the reviewed literature.

To address the three distinct research questions and to systematically compile obstacles and opportunities for old(er) workers in digital learning environments, we applied a *framework synthesis approach*—a method in which a suitable conceptual framework is derived from the literature, then adapted and further developed throughout the analytical process (Brunton et al., 2020). This theoretical framework is presented in detail in the following section.

The acquisition of new knowledge involves change processes (Aylward, 2012), unfolding in phases over time. This aligns with Kurt Lewin's (1947) three-stage Change Theory—*unfreezing*, *changing*, and *refreezing*—which we adapted for this review and research questions. Lewin's stages describe the progression from destabilizing existing routines and fostering motivation for change, through the implementation of new behaviors and mind-sets, to the eventual stabilization and reinforcement of the newly adopted practices (Lewin, 1947). While originally developed to capture organizational change, Lewin's framework can be applied and adapted to the specific context of (older) workers' engagement with digital learning environments. We use Lewin's model to define three contextually grounded learning phases—*prelude*, *engagement*, and *sustain* (Figure 2). These phases represent distinct temporal stages in the learning process and form the *framework guiding the synthesis* of our results.

In the following, we elaborate on each phase, relate them to Lewin's original stages, and show how our adaptation is informed by aging and later-life learning literature.

- (i) The *prelude phase* refers to the period preceding the commencement of training for old(er) workers and aligns with Lewin's 'unfreezing' by capturing the structural and/or motivational factors that influence old(er) workers' readiness and willingness to learn. Here, research has

Table 1. Characteristics of the publications included in the review.

Author(s)	Year	Pub. Type	Country	Age O	Ageism	Def. DL	Em- piric	Design	Samp. Size	Samp. Age	Samp. Gender
Ahmad and Tarmudi, (2012)	2012	CC	MYS	46+	D	Y	E	QT	100	MY,O	M,MF
Bai et al. (2020)	2020	SA	CHN	52+	D	N	E	QL	10	O	M,MF
Bausch, (2013)	2013	D	DEU	40+	C	N	E	QT	285/147/ 1101	Y,MO	M,MF
Becker et al. (2012)	2012	SA	AUS	44+	N	Y	E	QL	5 ^a	n/a	n/a
Bowman and Kearns, (2007)	2007	R	AUS	45+	C	N	E	QL	4 ^a	n/a	n/a
Brown, (2001)	2001	SA	USA	55+	D	Y	E	QT	78	MY,O	n/a
Cau-Bareille et al. (2012)	2012	SA	FRA	40+	C	N	E	QL	16	MY,O	n/a
Damico et al. (2022)	2022	SA	CAN	60+	D	N	E	QT	139	O	M,MF
Fleming et al. (2017)	2017	SA	AUS	45+	D	Y	E	QT	979	n/a	MM,F
Garavan et al. (2010)	2010	SA	IRL	45+	N	Y	E	QT	1500	MY,O	M,MF
Gaumer Erickson and Noonan, (2010)	2010	SA	USA	50+	N	N	E	MM	136	MY,O	M,MF
Haertel et al. (2015)	2015	CC	DEU	50+	C	N	E	QL	n/a ^b	n/a	n/a
Kriegel, (2013)	2013	D	USA	49+	N	Y	E	QT	765	MY,O	n/a
Lam and Chung, (2010)	2010	SA	CHN	55+	C	Y	E	MM	>50	O	n/a
Meyers and Bagnall, (2017)	2017	SA	AUS	45+	N	N	E	QL	10	O	M,F
Meyers, (2015)	2015	D	AUS	45+	C	Y	E	QL	10	O	M,F
Minge et al. (2014)	2014	CC	DEU	60+	D	Y	E	QL	94	O	n/a
Mokmin and Neoh, (2023)	2023	P	MYS	45+	N	N	E	QT	49	O	n/a
Naumanen and Tukiainen, (2008)	2008	CC	FIN	60+	N	N	E	MM	15	O	n/a
Pan and Pierre Lu, (2015)	2015	SA	USA	50+	C	N	E	QT	140	MY,O	n/a
Pappas et al. (2019)	2019	SA	GRC	55+	D	Y	E	QT	103	O	M,MF
Sieger et al. (2015)	2015	CE	DEU	50+	C	Y	E	QL	30	n/a ^b	M,MF
Struve and Wandke, (2009)	2009	SA	DEU	60+	D	N	E	QT	80	Y,O	M,F
Themistocleous et al. (2010)	2010	CC	UK, PRT, ESP, GRC	40+	N	N	E	QL	3 × 10- 14 ^c	O	n/a
Themistocleous et al. (2008)	2008	CC	UK, PRT, ESP, GRC	40+	D	Y	E	QL	n/a	O	n/a
Urlick, (2017)	2017	SA	USA	52+	C	N	E	QL	56	Y,O	n/a
Wallen and Mulloy, (2006)	2006	SA	USA	44+	C	N	E	QT	50	Y,O	n/a
Winston and Medlin, (2022)	2022	SA	USA	65+	C	N	E	QL	1 ^d	O	M
Bazley and Brooks, (2013)	2013	CC	USA	50+	C	N	NE	LO	n/a	n/a	n/a
Githens, (2007)	2007	SA	USA	56+	C	N	NE	LO	n/a	n/a	n/a
Gulliksson, (2022)	2022	CC	SWE	60+	D	Y	S	SR	n/a	n/a	n/a
Jones and Shelbourn, (2011)	2011	SA	UK, AUS	50+	C	Y	NE	LO	n/a	n/a	n/a
Plaza et al. (2013)	2013	CC	ESP	60+	C	N	NE	LO	n/a	n/a	n/a
Salter, (2014)	2014	BC	USA	55+	N	Y	NE	LO	n/a	n/a	n/a
Teichmann et al. (2019)	2019	SA	DEU	n/a	C	N	NE	LO	n/a	n/a	n/a
Towler and Mitchell, (2015)	2015	BC	USA	n/a	D	N	NE	LO	n/a	n/a	n/a
van Gerven et al. (2006)	2006	SA	NLD	n/a	D	N	NE	LO	n/a	n/a	n/a
Wolfson et al. (2014)	2014	SA	USA	55+	D	Y	NE	LO	n/a	n/a	n/a
Yamada et al. (2018)	2018	CC	JPN	n/a	N	N	S	SR	n/a	n/a	n/a
Ypsilanti et al. (2014)	2014	SA	GRC, UK, FIN, NLD	n/a	D	N	S	SR	n/a	n/a	n/a

^aCase study^bExpert workshop or survey^c3 classes with each 10 to 14 participants^dSingle case study over a period of 6 months.

Year – Year of publication; Pub. Type – Type of Publication; SA – Scientific article; D – Dissertation; R – Report; CC – Conference contribution; P – Preprint; CE – Collected edition; BC – Book chapter; Country – Country where the study (E) was conducted or where the authors are based (NE/S); MYS – Malaysia; CHN – China; DEU – Germany; AUS – Australia; USA – United States of America; FRA – France; CAN – Canada; IRL – Ireland; FIN – Finland; GRC – Greece; UK – United Kingdom of Great Britain and North Ireland; PRT – Portugal; ESP – Spain; SWE – Sweden; ITA – Italy; NLD – Netherlands; JPN – Japan; Age O – Age at which people are considered old(er); Ageism – Tonality of the study toward old(er) people; D – Deficit oriented; N – Neutral; C – Competence oriented; Def. DL – Definition of digital learning; Y – Yes, definition available; N – No, definition not available; Empiric – Is the publication empirical, non-empirical or systematically structured?; E – Empirical; NE – Not empirical; S – Systematic Work; Design – Design of the study; QT – Quantitative; QL – Qualitative; MM – Mixed methods (both quantitative and qualitative); LO – Literature overview; SR – Systematic review; R – Report; Samp. Size – Size of the Sample; Samp. Age – Ratio of old(er) to young(er) study participants; Y – Young; MY – Majority young; O – Old; MO – Majority old; Samp. Gender – Ratio of male to female study participants; M – Male; MM – Majority male; F – Female; MF – Majority Female; n/a – not available or not applicable.

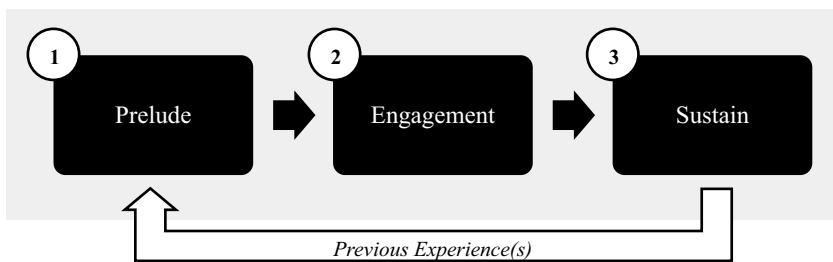


Figure 2. Flowchart of digital learning phases at company level.

shown that old(er) workers are frequently overlooked as the target audience for or – due to ageist perceptions – actively excluded from CVET. This results in fewer training opportunities and affects their motivation to participate. Furthermore, past learning experiences also influence their willingness to engage in future training (Froehlich et al., 2023; Naegele, 2020; Schmidt-Hertha et al., 2022).

- (ii) In contrast, the *engagement phase* encompasses the duration during which a worker is actively enrolled and participates in and engages with (digital) learning environments. It parallels Lewin’s ‘*change*’ stage, by focusing on the active experience of learning and its alignment with age-related preferences and needs in (digital) training environments. Here, geragogical scholars have emphasized that learning habits and preferences evolve over the life-course, underscoring the need to address the specific learning needs of old(er) workers (Formosa, 2002; Kolland & Wanka, 2013). This is particularly relevant for training transferred into the digital space (Baets et al., 2012; Bai et al., 2020; Bekisheva et al., 2017; Heenan, 2016).
- (iii) The *sustainment phase* follows the engagement with digital learning environments, focusing on applying the acquired knowledge. It mirrors Lewin’s ‘*refreezing*’, by emphasizing the transfer, application, and long-term integration of newly acquired knowledge into work practices. Until now, little is known about age effects on retaining this knowledge, but studies suggest old(er) workers prefer more guidance and support when subsequently applying what they have learned (Gaumer Erickson & Noonan, 2010; Struve & Wandke, 2009; Wolfson, 2014).

In addition to the temporal phases, we distinguished three interconnected levels of social interaction for our framework in order to capture the complexities of learning processes and how participants are integrated into them: (i) *macro-*, (ii) *meso-*, and (iii) *micro-level* (Figure 3). This helped to identify obstacles and opportunities in learning processes that lie at (i) the *individual level* (e.g., personal past experiences with learning or educational level), (ii) the *organizational level* (e.g., company incentives for educational participation, technological equipment, etc.), and at (iii) the *societal level* (e.g., negative stereotypes about aging, educational policy conditions) (Zawacki-Richter & Bozkurt, 2022).

To guide the synthesis of findings, we developed categories grounded in the aforementioned adapted framework. This framework was applied deductively to the included publications. Within these predefined categories, we subsequently conducted an inductive analysis to identify and elaborate additional subcategories emerging from the data (see Figure 4 in the section addressing the analysis and results). Conflicting findings were documented rather than resolved, as they were seen to reflect contextual differences and the complexity of age-appropriate digital learning.

The following section provides a descriptive overview of selected characteristics of the studies included in the review. We took this step not only because we expect the existing literature to be fragmented given that this is an emerging topic but also because the data sources and terminologies (‘older worker’ and ‘digital learning’) may vary widely across disciplines, study designs, and contexts. This approach helps deepen our understanding of the body of literature and the validity, strength, and generalizability of the findings, issues that we discuss in more detail in the discussion and limitations/outlook.

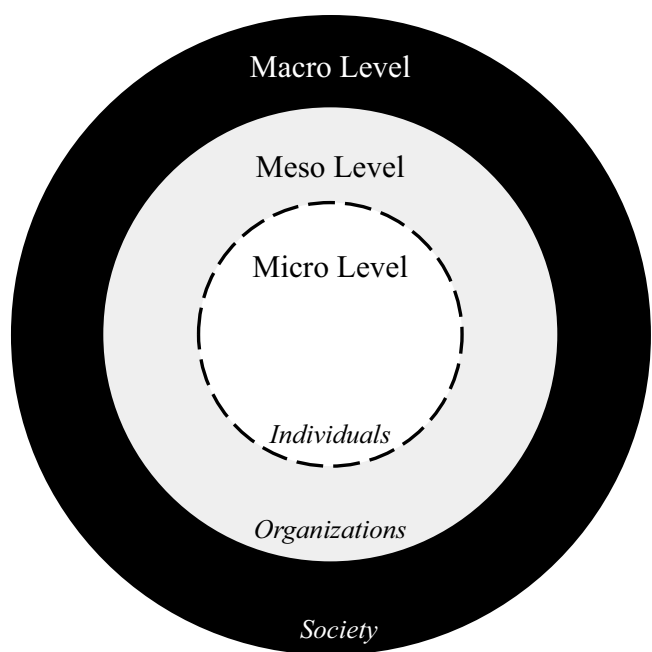


Figure 3. Levels of social interaction.



Figure 4. Global distribution of publications.

Characteristics of the included publications

Overall, we included 40 publications in the review (Table 1). The respective data corpus is predominantly constituted by publications with a Western perspective, where either the data (empirical studies, i.e., research that collects its own data) or the authors (non-empirical, i.e., literature overviews and some types of conference contributions or systematic writings, i.e., reviews) originated from Europe (52%), North America (26%) or Australia (12%) (Figure 4). Only a few publications emerged from Asian countries (10%).

Short Description: A world map showing the distribution of publications with varying circle sizes.

Long Description: The map illustrates the global distribution of publications, represented by circles of varying sizes. Larger circles indicate a higher concentration of publications. Notable clusters are visible in North America, and in Western Europe, with several circles indicating significant publication activity. Smaller circles are scattered across parts of Asia, Australia and other regions, indicating lesser but notable publication presence. The spatial pattern shows a concentration in developed regions, with sparse distribution in other areas.

The ‘oldest’ publication included in the review dates back to 2001. However, most of the publications were published after 2010 ($n = 28$; 70%) (Figure 5).

Short Description: A bar graph showing annual publication output by year within the 2,000s decade.

Long Description: The bar graph tracks the volume of scholarly work over a 25-year period from 2001 to 2025. The vertical y-axis measures the ‘number of publications’ on a scale from 0 to 6. The horizontal x-axis captures time (‘year within the 2,000s decade’), displaying two-year increments from ‘01 to ‘25. After a quiet start—recording only one publication in 2001 and zero from 2002 to 2005—output establishes a baseline of two annual publications between 2006 and 2008. Productivity surges during the 2010s, maintaining 3–4 publications annually before hitting an absolute peak of five publications in 2015. Following a decline to three publications in 2016 and a sharp drop to one in 2017, the final phase shows high volatility: a brief resurgence in 2018 (three publications) and 2019 (two publications) precedes a low trough in 2020–2021 (one publication each), a final spike of three publications in 2022, and zero output from 2023 through 2025.

In addition, the majority of publications were characterized as scientific articles respective journal articles ($n = 22$; 55%) whereby another comparatively large part of the data corpus consists of conference contributions ($n = 10$; 25%). Hence, a substantial proportion of the publications were based on empirical data ($n = 28$; 70%) thereof roughly as many qualitative ($n = 13$; 32, 5%) as quantitative ($n = 12$; 30%) and some mixed methods ($n = 3$; 7, 5%) studies—, whereby the remaining publications are either literature overviews ($n = 9$; 22, 5%) or reviews ($n = 3$; 7, 5%) (Figure 6).

Short Description: A pie chart illustrating the distribution of study designs.

Long Description: A pie chart illustrating the distribution of study designs across the total analyzed publications. The pie chart highlights the proportion of each methodology: Qualitative (QL, 32.5%), Quantitative (QT, 30.0%), and Literature Overviews (LO, 22.5%), followed by Mixed Methods (MM, 7.5%) and Systematic Reviews (SR, 7.5%).

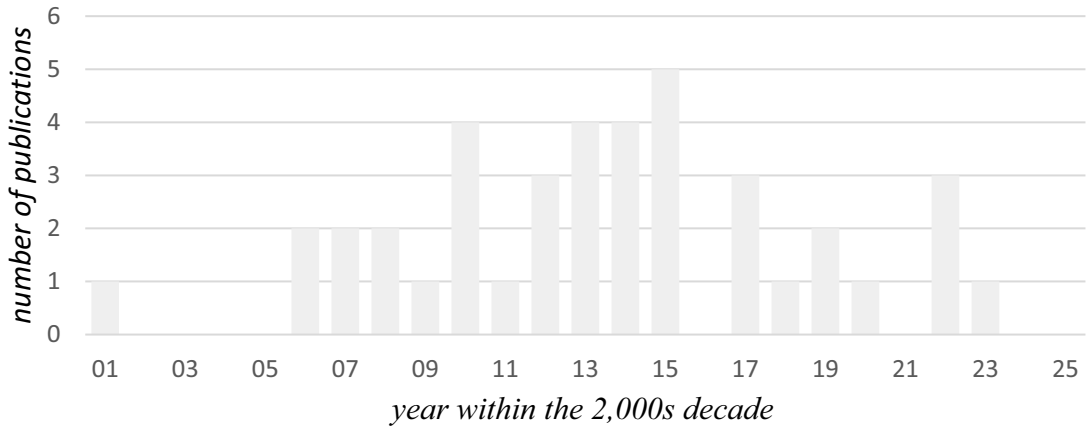
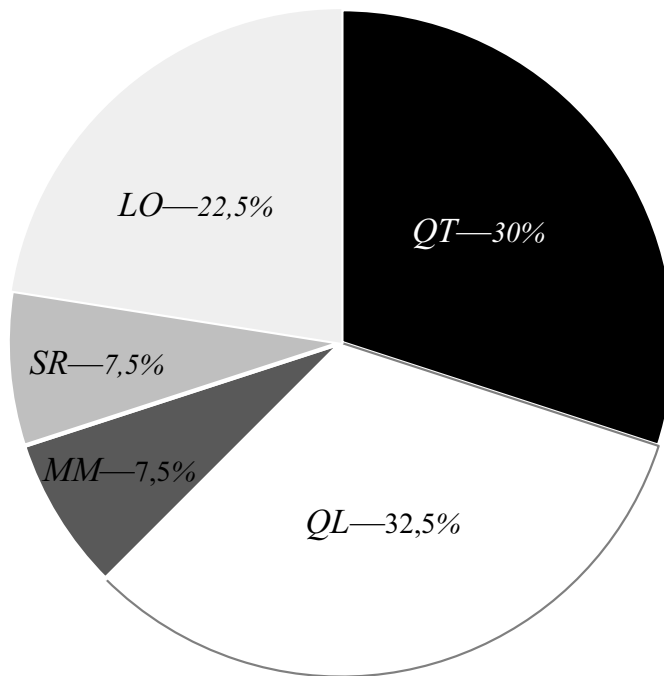


Figure 5. Annual publication output.



QT—Quantitative; QL—Qualitative; MM—Mixed methods (both quantitative and qualitative); LO—Literature overview; SR—Systematic review

Figure 6. Overview of study designs.

The quantitative studies in particular usually had relatively small sample sizes ($\emptyset \approx 420$) ranging from 49 to 1,500 participants, which were often not randomly selected. Additionally, the data is restricted to the extent that some studies surveyed young(er) people as the main group ($n = 7$; 25%) and the majority of participants were female ($n = 8$; 28, 6%) – in quite a few studies, no information was given in this regard (no information on sample size $n = 2$, no information on exact age composition $n = 5$, no information on gender distribution $n = 15$). Table 1 provides an overview and additional details regarding the included publications.

In the following, we address the terminology employed in the relevant literature, with a particular focus on how the terms ‘old(er) worker’ and ‘digital learning’ are defined and interpreted. Given that these terms are used inconsistently and are subject to varying interpretations, it is essential to delineate their meanings in the context of our review.

What it means to be an ‘old(er) worker’ (definition and Ageism)

This section outlines how the term ‘old(er) worker’ is defined in the publications and highlights how such definitions can reflect or reinforce ageist assumptions.

Instead of a life-span perspective, which views one’s progress through their career as a dynamic process influenced by biological, psychological, and social factors, chronological age is often used for simplicity and standardization (Kooij et al., 2008). Chronological age permits a straightforward identification of whether a worker belongs to a certain age is deemed to be old(er). However, this approach also entails the potential for (ageist) stereotyping, as it is susceptible to ‘overgeneralized expectations and beliefs about the characteristics and traits of individuals on the basis of age’ (Toomey

& Rudolph, 2015). Hence, it is of interest to examine how studies define ‘old(er) workers’ and which age-related stereotypes they reinforce, especially since old(er) adults are often unjustifiably seen as unwilling to learn and lacking digital skills.

The different publications included in the review specify the respective cutoff age between 40 and 65 years ($\emptyset \approx 51$). This relatively large difference is closely linked to contextual factors such as the current social structures, cultural region, socio-economic conditions, and/or the *zeitgeist* (Marques et al., 2020; Seyfried, 2011).

Besides, the underlying concept(s) of age(ing) also play(s) a major role in determining ‘the old(er) worker.’ The publications included in the review thus contain both: prospects that characterize aging primarily as a physical and psychological process of decline and transfer this to the area of cognitive performance ($n = 14$; 35%) as well as prospects with a far more differentiated view of age-related development and change processes (Höppner, 2021; Rupperecht, 2008; Stamov Roßnagel et al., 2010). Here, ageing is described as multidirectional and interactionist, whereby the consideration of competencies (Charbonnier & Roy, 2013) and the interaction with the requirements of a specific situation (Rupperecht, 2008) play a central role ($n = 16$; 40%). In addition, some publications did not delve into the age(ing) concept any further and were therefore regarded as neutral ($n = 10$; 25%).

About the different shapes of ‘digital learning’ (definition)

This section outlines how ‘digital learning’ is defined across the publications, emphasizing the variety of forms and interpretations the term encompasses.

‘Digital learning’ or ‘e-learning’ function as generic terms and therefore only offer a vague idea of the actual setup of the digital learning measure. According to Servage (2005, p. 306), “[a] good deal of the difficulty rests in failures to distinguish component aspects of e-learning”—in other words, things like goals, learners, content, teaching methods, and assessment are often mixed up or not clearly separated Servage (2005, p. 306). This inconsistency is also evident in the papers included in the review, as fewer than half of the publications included any definitions at all ($n = 16$; 40%), and those that did varied greatly in their complexity.

One publication (Wolfson et al., 2014), for example, defines ‘digital learning’ broadly as any technology-based training, while another publication (Ahmad & Tarmudi, 2012) describes ‘e-learning’ more specifically as technology-enabled instructional content, including web-based learning, computer-based learning, and virtual classrooms. Other examples of definitions used were serious games (Ypsilanti et al., 2014), learning programs with new media (Bazley & Brooks, 2013), computer-based training (Brown, 2001), or distance learning (Githens, 2007).

Analysis and results

We present results following the analytical framework (see the section addressing the synthesis). *First*, *macro-level* findings across all three temporal phases provide context for how institutions or companies (*meso-level*) and individuals (*micro-level*) approach digital learning (Pfau et al., 2014). *Then*, we discuss *meso-* and *micro-level* results separately for each research question, aligned with the temporal phases—*prelude*, *engagement*, and *sustain*—capturing unique dynamics and challenges at each level of social interaction.

Although important, the *macro-level* was rarely addressed in the publications analyzed (Figure 7). When addressed, the focus was on historical and/or cultural factors as well as stereotypes about lifelong learning, and their impact on old(er) workers’ engagement with digital learning.

Short Description: A bubble heatmap of publication counts across digital learning phases, social interaction levels and themes.

Long Description: A bubble matrix heatmap illustrating the number of publications in which each thematic category occurs, crossing the three digital learning process phases (prelude, engagement,

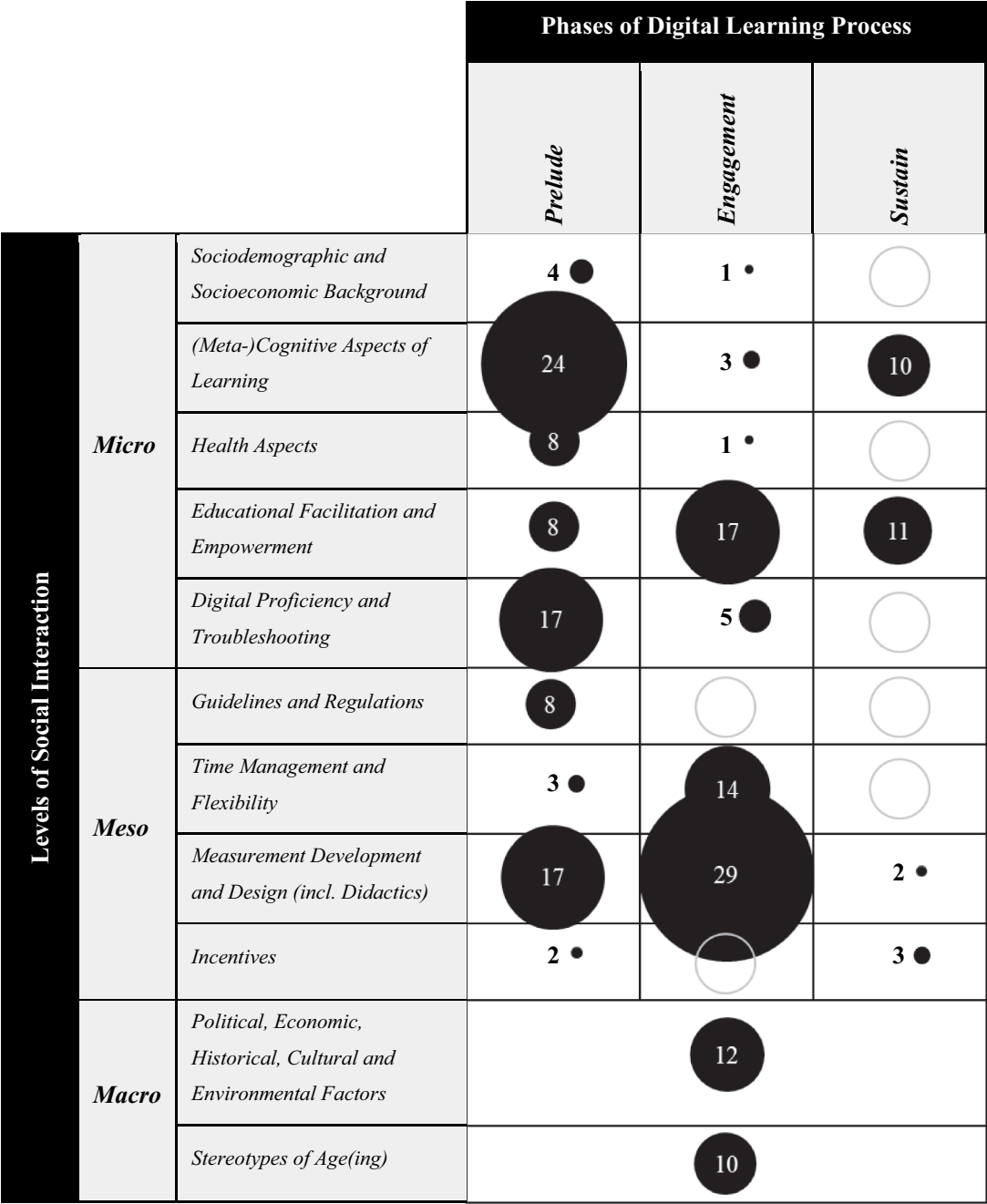


Figure 7. Heatmap of publication counts by phases of digital learning process, levels of social interaction, and thematic categories.

sustain) with three social interaction levels (micro, meso, macro). Within this matrix, bubble sizes and internal numerals indicate how often specific thematic categories—such as ‘digital proficiency and troubleshooting’ or ‘measurement development and design (incl. didactics)’—appear across the phases and levels. At the micro level, the identified categories occur most frequently within the prelude phase, driven primarily by ‘(meta-)cognitive aspects of learning’ (24) and ‘digital proficiency and trouble-shooting’ (17), though ‘educational facilitation and empowerment’ appears most often during

engagement (17). At the meso level, the ‘measurement development and design (incl. didactics)’ category dominates the dataset, appearing in 29 publications during engagement after a strong presence in prelude (17). On the macro-level research focuses entirely on broader systemic categories, specifically ‘political, economic, historical, cultural and environmental factors’ (12) and ‘stereotypes of age(ing)’ (10), which is why these overarching societal dimensions are not subdivided into temporal phases.

This is evident in 15 publications included in the review (Bai et al., 2020; Bazley & Brooks, 2013; Bowman & Kearns, 2007; Cau-Bareille et al., 2012; Garavan et al., 2010; Githens, 2007; Gulliksson, 2022; Jones & Shelbourn, 2011; Salter, 2014; Teichmann et al., 2019; Themistocleous et al., 2008, 2010; Wolfson et al., 2014; Yamada et al., 2018; Ypsilanti et al., 2014). One publication (Bai et al., 2020) finds that individuals raised during the Chinese Cultural Revolution had limited educational opportunities and developed a strong emphasis on formal credentials, which now hinders their adoption of digital learning in later life. Another publication (Gulliksson, 2022) highlights the importance of infrastructure, noting that broadband access depends on a country’s systemic and socioeconomic context.

RQ1: what factors contribute to the engagement of old(er) workers in digital learning measures?

We find that certain factors impact the likelihood of participation among old(er) workers during the *prelude phase*.

At the *meso-level*, this includes publications that address the framework conditions that involve a variety of factors in and around the company. These conditions include socio-economic factors (e.g., access to or availability of the necessary hardware/software, training opportunities, etc.) (Damico et al., 2022; Gulliksson, 2022). Additionally, company-wide regulations and job requirements trigger extrinsic motivation to remain employable (Bai et al., 2020; Garavan et al., 2010; Lam & Chung, 2010; Winston & Medlin, 2022). The policies mentioned above also encompass measures for executive and managerial awareness, anti-discrimination (Bazley & Brooks, 2013; Wolfson et al., 2014), and established incentive structures that provide workers with perceived benefits (Naumanen & Tukiainen, 2008; Themistocleous et al., 2008). Furthermore, effective time management is an advantage as digital learning, in particular, offers flexibility in terms of time and location (Bai et al., 2020). This makes it easier to combine it with responsibilities, such as caregiving duties, or issues with commuting (Salter, 2014; Themistocleous et al., 2010). In this regard, it is important to consider the needs of old(er) workers when developing digital learning measures (Themistocleous et al., 2008). One effective approach to do so is ‘co-creation,’ which involves the target group in the development process (Salter, 2014). Workshops can aid in creating a more structured approach, customizing the learning setting, and considering learning limitations and preferred formats (Bazley & Brooks, 2013; Naumanen & Tukiainen, 2008; Themistocleous et al., 2010).

At the *micro-level*, our review revealed that sociodemographic and socioeconomic characteristics such as gender, geographical location, educational level, work-related status, and household income, in addition to age, are relevant in order to keep older workers engaged in digital learning environments (Githens, 2007; Pappas et al., 2019; Salter, 2014). Additionally, age-related physical and cognitive changes such as reduced mobility, deteriorating eyesight and hearing, memory decline, and limited cognitive processing resources are frequently reported as barriers to participation in digital learning (Bai et al., 2020; Githens, 2007; Gulliksson, 2022; Naumanen & Tukiainen, 2008; Salter, 2014; Wallen & Mulloy, 2006; Yamada et al., 2018). However, these hindrances are often caused by one-sided preconceptions about age-related decline, rather than the actual physical and cognitive conditions of old(er) workers (Githens, 2007). These stereotypes can manifest themselves both (i) inter- and (ii) intrapersonally: (i) In terms of interpersonal factors, old(er) individuals can experience a lack of support from colleagues and supervisors, as well as missing respective inadequate communication and information (Bai et al., 2020; Bowman & Kearns, 2007;

Githens, 2007; Gulliksson, 2022; Jones & Shelbourn, 2011; Teichmann et al., 2019; Wolfson et al., 2014). Thus, according to one publication (Naumanen & Tukiainen, 2008), motivation to learn is primarily generated by other people: (ii) Intrapersonal, negative stereotypes can also affect the self-concept of those who are impacted (self-stereotyping) and influence their willingness to participate by building up inhibitions and fears (Bazley & Brooks, 2013; Bowman & Kearns, 2007; Cau-Bareille et al., 2012; Garavan et al., 2010; Githens, 2007; Gulliksson, 2022). These anxieties are also associated with the adoption and utilization of digital technologies (Bazley & Brooks, 2013; Wolfson et al., 2014; Ypsilanti et al., 2014). Sometimes, concerns are also based on trust issues and security apprehensions of old(er) workers (Gulliksson, 2022). Conversely, confidence, self-efficacy, and self-identification as ‘a learner’ are conducive factors for participating in CVET measure (Bazley & Brooks, 2013; Bowman & Kearns, 2007; Cau-Bareille et al., 2012; Garavan et al., 2010; Gulliksson, 2022; Salter, 2014; Themistocleous et al., 2010; Wolfson et al., 2014; Yamada et al., 2018).

However, during the *prelude phase*, the publications included in our review reveal it’s important to consider not only the self-perception and external perception of old(er) workers but also their perception of the learning measure and the technology used: Basically, the learning measure should serve specific goals (Pappas et al., 2019; Yamada et al., 2018), have an expected outcome (Ypsilanti et al., 2014), pursue a subjective respective content-related interest (Teichmann et al., 2019), and offer particular benefits (Naumanen & Tukiainen, 2008; Sieger et al., 2015) as well as ease of use (Garavan et al., 2010). At the same time, prior experience with digital technology is crucial, as it strongly influences the perception of usability (Meyers, 2015; Mokmin & Neoh, 2023; Teichmann et al., 2019; Yamada et al., 2018). When old(er) workers are required to use unfamiliar digital technologies, they typically need more time, extensive practice, and a positive attitude toward them (Bai et al., 2020; Ypsilanti et al., 2014).

In our adaptation of Lewin’s Change Theory (1947), the *prelude phase* represents the initial step where motivation is sparked, and existing attitudes and structures are questioned and loosened (‘unfreeze’), enabling changes especially in adopting new ways of working and learning. Key aspects include: (1) Ageist stereotypes reinforce the status quo, making the ‘unfreezing’ of entrenched self- and external perceptions a critical task (Bowman & Kearns, 2007; Githens, 2007; Jones & Shelbourn, 2011); (2) inter- and intrapersonal factors such as self-efficacy, learning motivation, and trust in technology serve as essential emotional drivers to initiate change, with emphasis on individual benefits like flexibility, employability, and personal growth further supporting readiness (Cau-Bareille et al., 2012; Garavan et al., 2010; Gulliksson, 2022; Salter, 2014; Yamada et al., 2018); (3) organizational measures – such as effective time management, co-creation, tailored learning formats, adequate technical infrastructure, and targeted support – help reduce resistance by fostering a learning environment perceived as safe, accessible, and relevant, which is vital for breaking habitual routines and mindsets (Bai et al., 2020; Bazley & Brooks, 2013; Naumanen & Tukiainen, 2008; Themistocleous et al., 2008, 2010; Wolfson et al., 2014); (4) finally, prior experiences with digital tools strongly influence self-assessment and engagement with new learning opportunities, where negative experiences or lack of access may cause rejection, thus necessitating low-threshold entry points during the *prelude phase* (Meyers, 2015; Mokmin & Neoh, 2023; Teichmann et al., 2019; Yamada et al., 2018).

RQ2: what adjustments in the delivery of digital learning are necessary to meet the learning needs and preferences of old(er) workers, while facilitating the acquisition of new knowledge?

In this section, we examine the *engagement phase*. This refers to the period during which the participant is actively enrolled in digital learning and acquiring new knowledge. In this regard, the relevant publications demonstrate that several adjustments are required to cater to the learning needs and preferences of old(er) workers, which are outlined below.

Many decisions are not a matter of individual planning, but rather influenced by a multitude of actors and occupational groups (e.g., IT specialists, managers, works councils, administrators,

purchasers, etc.) at the *meso level*. Firstly, the literature suggests that time management should be adapted to allow for longer time requirements and practice periods (Bazley & Brooks, 2013; Githens, 2007; Themistocleous et al., 2008; van Gerven et al., 2006; Ypsilanti et al., 2014), as old(er) workers tend to require more training than their younger counterparts (Cau-Bareille et al., 2012; Haertel et al., 2015; Naumanen & Tukiainen, 2008); also, the ability to control the amount of time spent on a task improves performance (Wolfson et al., 2014). In general, a self-directed approach is often recommended in terms of controlling the pace and which materials prove personally relevant or engaging, how information is presented (e.g., fonts, size, contrast, etc.), or which training formats are used (Cau-Bareille et al., 2012; Githens, 2007; Gulliksson, 2022; Minge et al., 2014; Salter, 2014; Teichmann et al., 2019; Themistocleous et al., 2008; van Gerven et al., 2006; Wolfson et al., 2014). Learning materials should also be presented in a clear, logical, and interesting way (Garavan et al., 2010; Pappas et al., 2019) and be of high quality (Bowman & Kearns, 2007). Multimedia materials are also usually emphasized positively (Githens, 2007; Pappas et al., 2019; Themistocleous et al., 2008; van Gerven et al., 2006; Winston & Medlin, 2022; Wolfson et al., 2014). At the same time, however, this should not lead to over-ornamentation and thus to an overload of information (Wallen & Mulloy, 2006). In particular, AI-supported learning environments could offer an opportunity to make training more user-specific (Wolfson et al., 2014). Closely linked to this is tailoring measures to the respective target group (e.g., older workers, practitioners, workers with a lower level of education, etc.) (Haertel et al., 2015). However, it should be noted that the desire for social exchange ought not be hindered by the possibility of learning at one's own pace.

In terms of learning methods, old(er) adults seem to prefer and benefit from practical training combined with realistic respective real work-related examples (Bazley & Brooks, 2013; Gaumer Erickson & Noonan, 2010; Pappas et al., 2019; Teichmann et al., 2019; Themistocleous et al., 2010; Urick, 2017; van Gerven et al., 2006; Wolfson et al., 2014; Yamada et al., 2018; Ypsilanti et al., 2014) to absorb the message conveyed by the theoretical part of the measures (Cau-Bareille et al., 2012). In this respect, social contextualization and situated learning should be encouraged (Wolfson et al., 2014). Old(er) workers have more difficulty learning completely new material than learning familiar material that builds on experiential knowledge (Wolfson et al., 2014). They also benefit from highly structured learning environments, i.e., clearly defined learning objectives, distinct and meaningful learning units, absence of unnecessary information, and short and varied modules (Gulliksson, 2022; Salter, 2014; Wolfson et al., 2014).

Last but not least, the technical design of digital learning environments should be as visually attractive (Githens, 2007), accessible, simple, and intuitive to use as possible (Haertel et al., 2015; Salter, 2014; van Gerven et al., 2006). The ability to make user-specific settings also appears to be beneficial (Wolfson et al., 2014).

At the *micro-level*, one should consider that the preferred learning method is strongly related to the sociodemographic and socioeconomic characteristics, as well as to previous experiences and the general self-concept of the learners (see also the section addressing RQ1) (Githens, 2007; Pappas et al., 2019; Salter, 2014). Nevertheless, it is evident from the field of geragogy that old(er) workers tend to favor interactive forms of learning over traditional, frontal learning (Bögel & Frerichs, 2011; Schmidt, 2006). This also applies to the digital space (Salter, 2014). In this context, it is similarly important to facilitate social interaction and collaborative learning (Bowman & Kearns, 2007; Haertel et al., 2015; Minge et al., 2014; Salter, 2014). Such an approach involves old(er) workers as capable experts in the learning process and recognizes their experience, which conveys appreciation (Haertel et al., 2015; Teichmann et al., 2019; Yamada et al., 2018). Conversely, ageist stereotypes can be mitigated through interpersonal interaction (Wolfson et al., 2014) and the fostering of a collective identity through the sharing of experiences (Bazley & Brooks, 2013; Salter, 2014). Examples of digital communication include the creation of personal profiles, sending messages (Githens, 2007), or exchanging in discussion forums (Gaumer Erickson & Noonan, 2010) and online communities (Bowman & Kearns, 2007). Concurrently, collaborative learning often facilitates (intrinsic) motivation, which is of paramount importance in determining participation and achieving success during the

learning process (Haertel et al., 2015; Wolfson et al., 2014). Furthermore, the enjoyment of digital learning materials is crucial (Minge et al., 2014).

To maintain high levels of motivation, an engaging and rewarding learning environment is necessary (Bowman & Kearns, 2007). Therefore, establishing active communication, allowing enough time for reflection, and providing support are crucial (Bowman & Kearns, 2007; Fleming et al., 2017; Garavan et al., 2010; Haertel et al., 2015; Meyers, 2015; Naumanen & Tukiainen, 2008; Pappas et al., 2019; Themistocleous et al., 2008; Yamada et al., 2018). This support should include the customization of the learning measures with positive and task-specific feedback (Wolfson et al., 2014) and adaptive guidance (Wolfson et al., 2014) as well as guidance on focal points (Wolfson et al., 2014), high-structure error correction (Struve & Wandke, 2009; van Gerven et al., 2006; Wolfson et al., 2014), and technology-related (peer) support (Bai et al., 2020; Fleming et al., 2017; Garavan et al., 2010; Gaumer Erickson & Noonan, 2010). The latter is of particular importance because digital technologies could act as a source of frustration, particularly for those who are less familiar with them (Bowman & Kearns, 2007; Garavan et al., 2010; Githens, 2007), e.g., issues from faulty equipment, discarded devices, poor internet connection, or short battery life should be avoided (Bai et al., 2020). However, it is recommended not to place too much importance on giving old(er) workers more choice, as they tend to benefit more from clear step-by-step guidance, whereas younger workers benefit more from having conceptual options (Wolfson et al., 2014). All learners should be encouraged to seek assistance from their peers and other sources (Cau-Bareille et al., 2012; Wolfson et al., 2014). Concurrently, trainers should aim to be perceived as organized and expressive, as this helps participants recall information (Towler & Mitchell, 2015), and strive to be accompanying and responsive (Bowman & Kearns, 2007) rather than patronizing (Teichmann et al., 2019).

In addition, health aspects and biological changes (e.g., memory issues, cognitive decline, sensory deficits, etc.) must certainly be considered (Bai et al., 2020; Githens, 2007; Gulliksson, 2022; Naumanen & Tukiainen, 2008; Salter, 2014; Wallen & Mulloy, 2006; Yamada et al., 2018), but this does not mean agreeing with a one-sided decline and thus ageist images of age(ing), as competencies gained in experience do indeed compensate (Heenan, 2016). Lastly, ergonomic aspects should be considered in general (Minge et al., 2014).

Building on the foundation established in the *prelude phase*, our developed *engagement phase* corresponds to Lewin's 'change' stage (1947), where individuals actively adopt new behaviors and knowledge following the initial 'unfreezing.' This phase requires tailoring learning environments and organizational practices to address the specific needs and behaviors of (older) workers. Our review identifies several key aspects critical for successful engagement: (1) flexible time management to integrate learning effectively into daily workloads (Bai et al., 2020; Salter, 2014; Themistocleous et al., 2010); (2) self-directed learning that allows learners control over pace, content relevance, and format (Cau-Bareille et al., 2012; Githens, 2007; Gulliksson, 2022; Minge et al., 2014; Salter, 2014; Teichmann et al., 2019; Themistocleous et al., 2008; van Gerven et al., 2006; Wolfson et al., 2014); (3) tailored learning materials that are clear, logically structured, high-quality, and often multimedia-enhanced (Bowman & Kearns, 2007; Garavan et al., 2010; Githens, 2007; Pappas et al., 2019; Themistocleous et al., 2008; van Gerven et al., 2006; Winston & Medlin, 2022; Wolfson et al., 2014); (4) practical, work-related training combined with realistic examples and social contextualization (Bazley & Brooks, 2013; Gaumer Erickson & Noonan, 2010; Pappas et al., 2019; Teichmann et al., 2019; Themistocleous et al., 2010; Urick, 2017; van Gerven et al., 2006; Wolfson et al., 2014; Yamada et al., 2018; Ypsilanti et al., 2014); (5) accessible, intuitive, and visually appealing technologies with options for user-specific customization (Githens, 2007; Haertel et al., 2015; Salter, 2014; van Gerven et al., 2006; Wolfson et al., 2014); (6) fostering social interaction and collaborative learning to enhance motivation and counteract ageist stereotypes (Bazley & Brooks, 2013; Bowman & Kearns, 2007; Haertel et al., 2015; Minge et al., 2014; Salter, 2014; Teichmann et al., 2019; Wolfson et al., 2014; Yamada et al., 2018); (7) continuous support through adaptive guidance, positive feedback, peer assistance, and technical help (Bai et al., 2020; Bowman & Kearns, 2007; Fleming et al., 2017; Garavan

et al., 2010; Githens, 2007; Gulliksson, 2022; Haertel et al., 2015; Jones & Shelbourn, 2011; Meyers, 2015; Naumanen & Tukiainen, 2008; Pappas et al., 2019; Teichmann et al., 2019; Themistocleous et al., 2008; Wolfson et al., 2014; Yamada et al., 2018); and (8) consideration of health and ergonomic factors without reinforcing negative age stereotypes (Bai et al., 2020; Githens, 2007; Gulliksson, 2022; Naumanen & Tukiainen, 2008; Salter, 2014; Wallen & Mulloy, 2006; Yamada et al., 2018). Together, these elements facilitate the transition from destabilized old routines to the adoption of new, effective learning practices.

RQ3: how can the long-term integration of newly acquired knowledge by old(er) workers be supported to ensure sustainable anchoring?

To address RQ3, we analyzed the *sustainment phase*—the final stage after (formal) digital learning ends focusing on knowledge retention and practical application through recurrent training or informal practices. However, most reviewed publications offered limited insights, indicating that this phase remains largely underexplored in existing literature.

At the *meso-level* (training design), old(er) workers appear to be amenable to the inclusion of further exercises following the conclusion of the learning measures (Cau-Bareille et al., 2012; Pappas et al., 2019). Furthermore, the distribution of summary documents could prove beneficial in facilitating the retention of significant insights from the learning process (Cau-Bareille et al., 2012).

At the *micro-level*, the subjective experience of learning success and personal satisfaction is of significant importance (Fleming et al., 2017; Teichmann et al., 2019). These factors influence the perceived effectiveness (Ypsilanti et al., 2014) and the enrollment rate of subsequent digital learning measures (Bai et al., 2020; Gaumer Erickson & Noonan, 2010). It can be observed that lower levels of recognized complexity have a beneficial effect on satisfaction, particularly in relation to the digital components of the learning measure (Fleming et al., 2017). Conversely, anxiety often leads to avoidance strategies, which challenge the establishment of routines regarding the newly learned knowledge (Cau-Bareille et al., 2012). In this context, educational facilitation and empowerment practices are beneficial (Garavan et al., 2010; Wolfson et al., 2014; Yamada et al., 2018; Ypsilanti et al., 2014). Above all, constructive feedback on past performances (reflection) and future use (guidance) should be provided (Bazley & Brooks, 2013; Garavan et al., 2010; Pappas et al., 2019; Teichmann et al., 2019; Wolfson et al., 2014; Yamada et al., 2018; Ypsilanti et al., 2014). To assess learning success, the implementation of self-evaluation (e.g., quizzes, practical questions, etc.) (Pappas et al., 2019) and evaluations are proposed (Bowman & Kearns, 2007; Sieger et al., 2015).

Building on the changes initiated in the *engagement phase*, the *sustainment phase* was adapted from Lewin's 'refreeze' stage (Lewin, 1947), where newly acquired knowledge and behaviors are embedded and stabilized after formal training. Our review highlights several key aspects essential for successful sustainment: (1) opportunities for continued practice and follow-up exercises to reinforce learning (Cau-Bareille et al., 2012; Pappas et al., 2019); (2) distribution of summary materials that aid retention of core insights (Cau-Bareille et al., 2012; Pappas et al., 2019); (3) self-evaluation tools such as quizzes and practical assessments to monitor progress (Bowman & Kearns, 2007; Pappas et al., 2019; Sieger et al., 2015); (4) constructive feedback focused on reflection and guidance for future application (Bazley & Brooks, 2013; Garavan et al., 2010; Pappas et al., 2019; Teichmann et al., 2019; Wolfson et al., 2014; Yamada et al., 2018; Ypsilanti et al., 2014); (5) fostering learner satisfaction and perceived success to support ongoing motivation (Bai et al., 2020; Gaumer Erickson & Noonan, 2010; Teichmann et al., 2019; Ypsilanti et al., 2014); (6) addressing anxiety and reducing complexity, especially regarding digital tools, to prevent avoidance behaviors (Fleming et al., 2017); and (7) empowerment through educational facilitation and peer support (Cau-Bareille et al., 2012; Garavan et al., 2010; Wolfson et al., 2014). Collectively, these elements promote the consolidation of new routines and the long-term application of digital learning, completing the behavioral shift initiated during the *engagement* ('change') phase.

Taken together, these findings describe how various factors across phases and levels influence older workers' engagement with digital learning environments and form the basis for the subsequent discussion, where they are interpreted through our adapted Change Theory framework.

Discussion and conclusion

Digitalization, AI, and demographic change have created a situation where an aging workforce must adapt to new skill demands (Komp-Leukkunen et al., 2022; Naegele & Ertl, 2023). This review is the *first to systematically examine age-appropriate digital learning environments*, identifying both challenges and opportunities for old(er) workers throughout the learning process. To interpret these findings and highlight their theoretical framing and practical implications, we draw on our adapted framework based on Lewin's three-phase Change Theory.

Regarding *RQ1 (prelude phase)*, we found that company- and meso-level factors play a major role in motivating old(er) workers to engage in digital learning. These include access to technology, training opportunities, (financial) incentives, company policies, and job requirements (Bai et al., 2020; Bazley & Brooks, 2013; Damico et al., 2022; Garavan et al., 2010; Gulliksson, 2022; Lam & Chung, 2010; Naumanen & Tukiainen, 2008; Sieger et al., 2015; Themistocleous et al., 2008; Winston & Medlin, 2022; Wolfson et al., 2014). Our findings align with previous research, such as that of Neycheva (2024), who highlights similar factors influencing participation in company-provided CVET. Neycheva (2024) specifically emphasizes the importance of management awareness, a supportive learning culture, and implementing anti-discrimination policies points strongly supported by our own review.

At the *micro-level*, our results confirm earlier research showing that age-related stereotypes can increase perceived physical and cognitive barriers to (digital) learning (Bazley & Brooks, 2013; Bowman & Kearns, 2007; Cau-Bareille et al., 2012; Garavan et al., 2010; Githens, 2007; Gulliksson, 2022), as also documented by Strobel et al. (2011) and Kolland and Ahmadi (2010). We also found that lack of managerial and colleague support, self-doubt, and fear of technology can discourage participation in (digital) CVET (Bai et al., 2020; Bazley & Brooks, 2013; Bowman & Kearns, 2007; Githens, 2007; Gulliksson, 2022; Jones & Shelbourn, 2011; Naumanen & Tukiainen, 2008; Wolfson et al., 2014; Ypsilanti et al., 2014). These findings echo the importance of a supportive environment and individual self-efficacy, as noted by Naujokaitiene et al. (2015) and Zhenga et al. (2018).

On the other hand, confidence, self-efficacy, and a learner mind-set promote participation in (digital) CVET (Bazley & Brooks, 2013; Bowman & Kearns, 2007; Cau-Bareille et al., 2012; Garavan et al., 2010; Gulliksson, 2022; Salter, 2014; Themistocleous et al., 2010; Wolfson et al., 2014; Yamada et al., 2018). Campbell et al. (2020) and Kyndt and Baert (2013) underline the positive impact of these psychological resources. Cruce and Hillman (2012) also found that each additional year of schooling increases the likelihood of old(er) adults joining work-related courses.

Together, these findings (Campbell et al., 2020; Cruce & Hillman, 2012; Kolland & Ahmadi, 2010; Kyndt & Baert, 2013; Naujokaitiene et al., 2015; Strobel et al., 2011; Zhenga et al., 2018) stress the need to tackle ageist stereotypes and strengthen companies' learning cultures.

Our review also shows that technology may have an additional influence on participation in learning measures (*prelude phase*), as prior experience with digital tools also affects perceived usability (Meyers, 2015; Mokmin & Neoh, 2023; Teichmann et al., 2019; Yamada et al., 2018). However, this should be interpreted with caution. For example, Butcher and Sumner (2011) suggest that more tech-savvy learners may overlook helpful supporting material. Based on this, we recommend that practitioners provide initial training, guidance material, constructive feedback, and technology-related support. Furthermore, Ang et al. (2018) argue that digital technologies can connect informal to formal learning something particularly relevant for old(er) workers: Although studies like Jenkins and Mostafa (2015) and Villar and Celdrán (2013) were not included in our review, they support the idea that informal learning is especially beneficial for old(er) adults.

Flexibility is another key factor flexible digital learning helps balance work, personal responsibilities, and ongoing learning (Bai et al., 2020; Salter, 2014; Themistocleous et al., 2010). Radovan (2024) draws

similar conclusions, emphasizing the value of flexible working arrangements and time management in promoting (digital) CVET. This is especially important for workers with unpaid caregiving responsibilities, as shown by Banbridge and Townsend (2020). Koreshi and Alpass (2022) also note that greater workplace flexibility facilitates prolonged employment among old(er) workers. We therefore recommend offering flexible working arrangements such as flexible hours and remote work options wherever possible.

In summary, to initiate the ‘unfreezing’ process in the *prelude phase* and prepare (older) workers for participation in digital CVET, the following must be addressed: overcoming age-related stereotypes, strengthening self-efficacy and motivation, ensuring organizational support with flexible and accessible learning options, and providing low-threshold access to digital tools to counteract negative prior experiences. These aspects are critical for initiating successful change implementation in the next phase.

To meet the needs of old(er) workers and support knowledge acquisition in digital learning (*RQ2/engagement phase*), we found that training should allow for extended practice and self-paced learning (Bazley & Brooks, 2013; Bowman & Kearns, 2007; Githens, 2007; Gulliksson, 2022; Haertel et al., 2015; Themistocleous et al., 2008, 2010; van Gerven et al., 2006; Ypsilanti et al., 2014). Therefore, we recommend integrating practical and real-world examples into learning programs, as they connect with old(er) workers’ learning needs and build on their experiential knowledge (Wolfson et al., 2014). We also suggest favoring interactive and collaborative methods, since our review has shown that social engagement enhances motivation, mitigates stereotypes, and fosters a sense of expertise (Naumanen & Tukiainen, 2008; Wolfson et al., 2014).

Trainers should be organized and responsive rather than patronizing, which is especially important for old(er) workers (Bowman & Kearns, 2007; Teichmann et al., 2019; Towler & Mitchell, 2015). Sharpe and Elwood (2024), though not workplace-focused, found that old(er) adults aged 55 and over benefit from interactive features and personalized feedback, given the apparent value of human interaction among old(er) learners. Additionally, they also recommend course structures that allow for flexibility and learning at the pace of old(er) adults, including step-by-step instructions (Sharpe & Elwood, 2024). Derksen et al. (2015) further support the importance of collaborative social interaction in learning environments, suggesting it helps with memory challenges that have been associated with aging.

Building on the foundation laid in the *prelude phase*, in the *engagement phase*, individuals begin adopting new knowledge and behaviors. The key factors identified – such as flexible time management (Bai et al., 2020; Bazley & Brooks, 2013; Githens, 2007; Themistocleous et al., 2008; van Gerven et al., 2006; Wolfson et al., 2014; Ypsilanti et al., 2014), self-directed and tailored learning (Bowman & Kearns, 2007; Cau-Bareille et al., 2012; Garavan et al., 2010; Githens, 2007; Gulliksson, 2022; Haertel et al., 2015; Minge et al., 2014; Pappas et al., 2019; Salter, 2014; Teichmann et al., 2019; Themistocleous et al., 2008; van Gerven et al., 2006; Winston & Medlin, 2022; Wolfson et al., 2014), practical content (Bazley & Brooks, 2013; Gaumer Erickson & Noonan, 2010; Githens, 2007; Pappas et al., 2019; Teichmann et al., 2019; Themistocleous et al., 2008, 2010; Urick, 2017; van Gerven et al., 2006; Wolfson et al., 2014; Yamada et al., 2018; Ypsilanti et al., 2014), accessible technology (Githens, 2007; Haertel et al., 2015; Salter, 2014; van Gerven et al., 2006), social interaction (Bowman & Kearns, 2007; Haertel et al., 2015; Minge et al., 2014; Salter, 2014; Wolfson et al., 2014), ongoing support (Bowman & Kearns, 2007; Fleming et al., 2017; Garavan et al., 2010; Haertel et al., 2015; Meyers, 2015; Naumanen & Tukiainen, 2008; Pappas et al., 2019; Themistocleous et al., 2008; Yamada et al., 2018), and health considerations (Bai et al., 2020; Githens, 2007; Gulliksson, 2022; Naumanen & Tukiainen, 2008; Salter, 2014; Wallen & Mulloy, 2006; Yamada et al., 2018) – are crucial to making the adoption of new habits as smooth as possible and to supporting the specific needs of (older) workers. These elements help ease the transition from destabilized old routines to effective new practices. Following this, the *sustainment phase* (Lewin’s ‘refreeze’ stage) solidifies and integrates these new behaviors into everyday work.

To support the retention and application of newly acquired knowledge (*RQ3/sustainment phase*), we found that old(er) workers benefit from summary documents and follow-up exercises (Cau-Bareille et al., 2012; Pappas et al., 2019). This is in line with Caffrey and Commins (2023), who found that spaced learning over a longer interval improves learning, regardless of age.

Our review also shows that learners' experiences—such as feeling successful and satisfied—significantly affect how they perceive the training to be and whether they will participate in the future (Bai et al., 2020; Fleming et al., 2017; Gaumer Erickson & Noonan, 2010; Teichmann et al., 2019). Määttä et al. (2016) identified several factors that influence learning success: (1) positive emotions, (2) effective working methods, (3) experiences of achievement, (4) acknowledgment from peers and trainers, and (5) previous experiences and skills. Based on this, we recommend using supportive strategies like constructive feedback, self-evaluation, and (peer) reflection to enhance retention and confidence. In this context, practitioners should utilize socially inclusive formats that facilitate interaction among individuals, particularly in instances where the transmission of facts is not the sole objective.

To embed and stabilize new knowledge from the *engagement phase* (Lewin's 'change' stage) in the *sustainment phase* (Lewin's 'refreeze' stage), key actions include providing ongoing practice (Bazley & Brooks, 2013; Githens, 2007; Themistocleous et al., 2008; van Gerven et al., 2006; Ypsilanti et al., 2014), follow-up exercises/summary materials (Cau-Bareille et al., 2012; Pappas et al., 2019), and self-evaluation tools (Bowman & Kearns, 2007; Pappas et al., 2019; Sieger et al., 2015). Constructive feedback (Garavan et al., 2010; Pappas et al., 2019; Teichmann et al., 2019; Wolfson et al., 2014; Yamada et al., 2018; Ypsilanti et al., 2014) and learner support (Cau-Bareille et al., 2012; Garavan et al., 2010; Gulliksson, 2022; Salter, 2014; Yamada et al., 2018) foster reflection and motivation, while addressing anxiety (Cau-Bareille et al., 2012) and simplifying digital tools (Haertel et al., 2015; Salter, 2014; van Gerven et al., 2006) reduces avoidance. Empowerment through facilitation and peer support further helps establish lasting learning routines (Bai et al., 2020; Cau-Bareille et al., 2012; Fleming et al., 2017; Garavan et al., 2010; Gaumer Erickson & Noonan, 2010; Teichmann et al., 2019; Wolfson et al., 2014; Ypsilanti et al., 2014).

From a managerial perspective, our findings provide actionable guidance for designing age-appropriate digital CVET. HR practitioners and training managers should foster inclusive learning cultures that counteract ageist stereotypes, offer flexible time arrangements, and ensure accessible digital tools. Co-creation with old(er) workers can help tailor content and interfaces to their preferences, while continuous feedback and peer support enhance confidence and engagement. Together, these measures promote sustained participation and knowledge transfer among an aging workforce.

In addition to practical insights, the review offers a theoretical contribution by refining Lewin's Change Theory for the context of digital learning among old(er) workers. Our findings extend Lewin's model by shifting its focus from organizational transformation to individual learning in later life. The adapted phases—*prelude*, *engagement*, *sustain*—illustrate how older workers unfreeze established routines, adopt new digital skills, and stabilize these changes over time. Integrating geragogical insights adds an age-specific dimension to Lewin's framework, highlighting learning as a continuous process of adaptation within an aging workforce.

Limitations and directions for future research

The study has several limitations, so its findings should be generalized with caution and recommendations applied in a context-specific manner. At the same time, these limitations highlight areas that future research can address, helping to fill gaps in the evidence.

First, the current literature is rather fragmented; this may partly be caused or influenced by unavoidable constraints in the research process: Only papers published up to June 2025 and the first 100 Google Scholar results per search string were considered, limiting the scope amid rapid developments in digital learning and compounded by definitional inconsistencies in key terms, which

may have introduced selection bias. In addition, the study partially relied on a qualitative assessment, addressed through a blind review process with at least two independent reviewers (see also the section addressing eligibility criteria and selection process). While this approach does not fully eliminate potential biases, especially considering that in qualitative research, professional experiences and assumptions, as well as disciplinary background, may inherently have influenced the research process. A final limitation concerns the varying confidence in our synthesized findings. Using qualitative judgments based on the 11-item appraisal tool (see also the section addressing quality assessment), we assessed confidence across methodological quality, coherence, data richness, and relevance for each learning phase. Confidence is moderate to *high for the prelude phase*, supported by numerous consistent studies; *moderate for engagement*, reflecting heterogeneous designs and some inconsistencies; and *low for sustainment*, due to scarce evidence on long-term retention. These levels indicate that findings for earlier learning stages are comparatively reliable, while conclusions about long-term knowledge integration should be interpreted with caution.

Second, due to the time lag in publication processes, an increase in publications reflecting the impact of the COVID-19 pandemic on digital learning is to be expected in the future. During the pandemic, the far-reaching restrictions especially in the initial phase of the pandemic led to face-to-face events being canceled, educational institutions being closed, and digital formats being newly developed (Kohl & Denzl, 2022). Yet, it is still unclear what long-term developments can be expected from this rapid digitalization of CVET measures. Hence, the fragmented nature of the evidence identified, and given the rapid advancements in artificial intelligence (AI), we recommend updating and expanding the scope of research in this domain within the next few years.

Third, the studies identified often lack representativity, with an overrepresentation of young(er) individuals as well as women among study participants. This limits data representativeness and the ability to draw broad conclusions about digital learning from the existing body of literature (yet). In addition, it is notable that most publications included in this review do not compare the learning needs of old(er) to those of other age groups e.g. young(er) workers. Without such comparative analyses, important distinctions in learning preferences, barriers, and outcomes across age groups may be overlooked, limiting the ability to tailor digital learning interventions effectively. Therefore, future research should involve both age groups to identify age-specific patterns in digital engagement and learning. In addition, these future studies should explicitly strive for balanced gender representation to explore potential gender differences in digital engagement, access, and outcomes. Explorative age-specific group discussions would be well-suited to uncover these nuanced experiences and needs. The findings from such qualitative research could then be validated and generalized through representative quantitative studies, thereby providing a more robust evidence base to inform tailored digital learning interventions. Future research designs might also consider longitudinal approaches to track how different age and gender groups adapt over time.

Fourth, the majority of studies offer limited information regarding contextual factors, such as country or business sector-specific settings. Often originating from a single, in most cases Western country, the studies don't take into account that there are significant differences in training participation between blue-collar and white-collar workers (Hurst, 2008), a gap that the digital component has the potential to widen. Future research should therefore broaden its scope to include a wider range of cultural and national contexts, place greater emphasis on sector-specific differences, and explore how digital learning may affect training participation and learning needs among different groups of old(er) workers across sectors. Quantitative studies would be particularly valuable in this regard, as they can generate representative data to complement and validate existing qualitative findings.

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Author contribution

Selina Staniczek, Laura Naegele, and Wiebke Schmitz were responsible for designing and conceptualizing the study, as well as curating and collecting the data. Selina Staniczek performed the formal data analysis, interpreted the results, and drafted the article. Laura Naegele contributed to securing funding and was involved in writing and revising the manuscript.

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