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ORIGINAL PAPER

Navigating Through the Digital Workplace: Measuring Leader Digital Competence

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Abstract

In a modern digital workplace, leaders must have the necessary skills to lead employees virtually. Despite its high practical and theoretical relevance, a consensus on crucial digital competencies for virtual leaders is lacking, hindering a systematic exploration of the leader's role in facilitating technology use. In the present article, we propose a new concept and instrument to assess leader digital competence (LDC). After reviewing the literature, we establish three dimensions of LDC, centering around the leader's ability and inclination to select, promote, and enable technology and digital media among their employees. We provide support for the scale's convergent, discriminant, criterion-related, and incremental validity using four independent samples ($N_1 = 156$, $N_2 = 309$, $N_3 = 201$, $N_{4\ \text{employee}} = 452$, $N_{4\ \text{leader}} = 93$). Furthermore, results support the reliability and factor structure with the three proposed dimensions of the 10-item LDC scale. The findings demonstrate that the scale represents a psychometrically sound instrument, useful for further examining conditions for effectiveness in the virtual environment. Future research should aim to advance the understanding of antecedents and situational factors that influence the relevance of LDC and its impact on employee, team, and organizational outcomes.

Keywords Computer-Mediated Communication · Digital Competence · Digital Leadership · Digital Media · E-Leadership · Scale Development · Scale Validation · Technology · Virtual Leadership

The ongoing digitalization process in organizations influences how leaders and team members collaborate (e.g., Banks et al., 2022). The shift towards greater reliance on new technologies and digital media (e.g., email, chat systems, or online platforms) for interaction and collaboration increases the complexity of group processes and carries significant implications for work teams and leader–follower interactions (Larson & DeChurch, 2020). In the organizational context, leaders are perceived as role models who establish standards for their employees by exhibiting desired actions and behaviors (e.g., Jaussi & Dionne, 2003). Thus, in the modern digital workplace, it falls upon the leader to establish functional structures for effective technology use, remain aware of the evolving framework conditions, and possess the right skill set (e.g., Contreras et al., 2020; Roy, 2012). Considering leader competence in using technology is pivotal when examining modern leadership practices, as technology and leadership are closely intertwined (Landers & Marin, 2021).

The shift in the primary mode of interaction between leaders and their teams, and subsequently, how influence is wielded, represents a major break that challenges our understanding of the leader's role and the needed competencies for achieving success in the digital era (Contreras et al., 2020; Tuschner et al., 2022). To explicitly capture this evolving context for leaders regarding the growing reliance on digital media for leadership processes, new terminologies have emerged, such as "digital leaders" (Claassen et al., 2021), "virtual leaders" (Liao, 2017), or "e-leaders" (Avolio et al., 2014). In this article, we refer to *virtual leaders* as leaders who strongly rely on technologies for interaction and overall leadership (Schmidt, 2014). Our primary focus is on the competencies in the context of technology use (as opposed to geographical dispersion or cultural differences; Schulze & Krumm, 2017), due to its high relevance for leaders across various industries as work arrangements become increasingly flexible and new technological opportunities emerge.

Additional supplementary materials may be found here by searching on article title https://osf.io/collections/jbp/discover.

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More generally, competence is conceptualized as the interplay of skills, knowledge, and attitudes (e.g., Baartman & de Brujin, 2011). However, less consistency exists around the term, *digital competence* (Murawski & Bick, 2017; Oberländer et al., 2020). Existing digital competence frameworks in the organizational context (e.g., Oberländer et al., 2020; van Laar et al., 2020) frequently span a wide spectrum of competencies, ranging from basic skills (e.g., using basic software and applications or searching and evaluating information) to advanced proficiency levels (e.g., communicating or collaborating using digital media). Previous attempts to measure leaders' digital competence in the virtual context are either specific to middle or upper management (e.g., Roman et al., 2019; Zeike et al., 2019); developed in the context of specific industries (e.g., Claassen et al., 2021); focus on skills relevant for enabling digital business models and digital transformation (e.g., Abbu et al., 2022; Borah et al., 2022; Nasution et al., 2020; Zeike et al., 2019), or encompass a wide range of leadership skills that are not unique to the shift to the virtual environment (e.g., trust or team building; Roman et al., 2019; van Wart et al., 2019).

The past attempts to combine all potential aspects of digital competence resulted in its fuzziness (Eberl & Drews, 2021), its generic and temporally constrained nature (due to new technological advancements), and the irrelevance of certain aspects for some employees (e.g., programming skills; Oberländer et al., 2020). A solid framework and scale for measuring leaders' digital competence is lacking, which impedes the development of a holistic understanding of the characteristics, underlying mechanisms, and consequences of it. Moreover, the existing measures for leaders' digital competence are in their early stages, necessitating more comprehensive development and validation, given the high practical relevance of virtual leadership. Therefore, our objective is to identify competencies for virtual leaders that are relevant and unique to the virtual context and concentrate on the competencies that arise due to the increased reliance on technologies (Krumm & Schulze, 2017; Schulze & Krumm, 2017; Schulze et al., 2017).

In the present study, we aim to address this gap in the literature and propose a new construct, namely Leader Digital Competence (LDC). We focus on the technology-related challenges to virtual work only and not on associated challenges such as building trust or relationships. This is to avoid conflating the cause with the effect, given that a plethora of research suggests that the inadequate use of digital media is frequently the root of difficulties in building trust and strong relationships (e.g., Malhotra et al., 2007; Norman et al., 2019; Walther & Bunz, 2005), or achieving high performance (Newman et al., 2020). We contribute to the literature by providing a comprehensive conceptual definition and building a nomological network around LDC, enabling an enhanced and more holistic understanding of it. By developing a measurement scale, we hope to contribute to a more systematic and reliable empirical assessment of the antecedents and outcomes of critical leader competencies that are unique and pressing to the virtual environment.

To develop a definition and scale of LDC, we first introduce technology-related theoretical approaches that have been proposed in the past. Second, we explore how virtuality brings new challenges and needs to virtual teams and how the leader's tasks, role, and required competencies change as a result. Third, based on the literature, we offer a conceptual model of LDC and focus on the leader's competence in selecting, using, and promoting technologies. Fourth, along with that, we propose a definition of LDC and develop a nomological network that systematizes related constructs (Fawcett et al., 2014; Suddaby, 2010), also including boundary conditions and outcomes. Fifth, we develop and validate an instrument to measure LDC from an employee perspective using four independent samples. Finally, we discuss the results and their implications for LDC, its nomological network, and proposed related constructs.

Literature Review

Technology in the Digital Workplace

In today's workplace, work and technology are intertwined, with technology having an undeniable impact on the organization and design of work (Landers & Marin, 2021). Technical innovation has the potential to fundamentally alter the nature of work (Schwarzmüller et al., 2018) and technologies are used as a medium to meet the objectives of virtual teams. For example, various communication or collaboration technologies can be selected and used as a medium to work on joint objectives. At the same time, the effectiveness of digital media depends on their alignment with situational needs (e.g., employee or team needs; Larson & DeChurch, 2020). This means that the reliance on digital media and virtuality in teams is not inherently negative or positive (Purvanova & Kenda, 2022) but depends on surrounding factors (e.g., on leadership; Brown et al., 2021). This notion stands in contrast to the long research tradition focusing on the rather deterministic and technocentric view, suggesting that the outcome of using a specific digital medium is bound to its capabilities (e.g., media richness theory or the reduced social cues model, Daft & Lengel, 1986; Kiesler et al., 1984). To examine the effect of technology on work processes and outcomes, it is therefore pivotal to not only concentrate on the tools used but also on *how* they are used (Landers & Marin, 2021). As leaders play a crucial role in creating the structures, understanding, and context in which a team operates (Schmidt, 2014), our specific focus lies on the leader's ability to facilitate technology use, particularly

in terms of promoting, enabling, choosing, and utilizing technology.

The growing body of evidence highlights that the positive or negative impact of technology on virtual team effectiveness is contingent upon the way they are selected, used, and enabled among team members (Krumm & Schulze, 2017; Schulze & Krumm, 2017; Swart et al., 2022). Navigating and providing direction in the virtual environment has been discussed as one of the biggest challenges for leaders in the virtual workplace (Morrison-Smith & Ruiz, 2020). A leader's behavior concerning media and technology use, including their choice of digital media and norms for dealing with them, has a significant impact on their followers' attitudes and behaviors (Braun et al., 2019; Schwarzmüller et al., 2018). Leaders must therefore deliberately employ technologies and implement associated structures in such a way that they meet the team members' needs to bring about the desired end states (Larson & deChurch, 2020).

Technology-Related Challenges and Needs

To develop a framework for LDC, we started off by identifying the biggest challenges and needs associated with virtual work (see Schulze & Krumm, 2017, for a similar approach). We argue that the responsibility for navigating the technology-related challenges posed by virtuality does not solely rest with employees who must possess the right knowledge, skills, and motivation. Instead, we assert that leaders bear a particularly important role in facilitating work within the digital era; they can be seen as enablers of effective technology use, helping the team navigate through the virtual environment (Blackburn et al., 2003; Walvoord et al., 2008). Based on an extensive review of the literature, three common themes of challenges and needs related to technology use were identified.

The first challenge surrounds the difficulties in effective virtual communication due to digital media use (e.g., Schulze & Krumm, 2017). In the past, digital media were assumed to go hand in hand with certain capabilities (e.g., their richness or ability to transmit social cues; Daft & Lengel, 1986), which can facilitate or hinder effective communication. However, this deficient view of digital media is often challenged, and multiple studies point out that factors such as tenure regarding media use or individual user characteristics can enhance media richness perceptions (e.g., Carlson & Zmud, 1999; Pieterson et al., 2008). Consequently, the difficulty does not lie in the inherent capabilities but rather in the appropriate selection of digital media regarding situational needs (Larson & deChurch, 2020). Associated challenges are difficulties arising from asynchronous communication (e.g., Morrison-Smith & Ruiz, 2020) or ambiguity due to the reduced transmission of visual, social, or non-verbal cues (e.g., Lee-Kelley & Sankey, 2008; Morrison-Smith & Ruiz, 2020; Swart et al., 2022; Walvoord et al., 2008). These examples are often bound to the inappropriate selection of digital media in the light of the task or context at hand (e.g., Driskell et al., 2003; Hertel et al., 2005; Schulze & Krumm, 2017) or the irregular or lack of communication (e.g., Daim et al., 2012; Morrison-Smith & Ruiz, 2020).

A second challenge concerns the short-livedness and rapid advancement of technologies, combined with the need to constantly adapt to these novel technologies (Cascio & Montealegre, 2016; Peschl & Schüth, 2022). New technologies are introduced at an ever-faster pace, and in many teams, a plethora of digital tools are used (Statista Research Department, 2022). Furthermore, a stable technological infrastructure and adaptability to novel tools are needed to ensure coordinated exchange (Aritz et al., 2018; Demirel, 2020). Frequently mentioned hurdles in this context are challenges related to individuals' motivation and attitude, such as a negative attitude, fear, or even avoidance of technology use (e.g., Brown et al., 2004; Krumm & Schulze, 2017; Scott & Timmerman, 2005), and the need to keep up with technical progress (Murawski & Bick, 2017). Being able to use one single technology is not sufficient; rather, flexibility and adaptability is required when it comes to the use of technologies (e.g., Blackburn et al., 2003; Oberländer et al., 2020; Spitzberg, 2006). Along with that is the openness and willingness "to learn to use new technologies to their full potential" (Blackburn et al., 2003, p. 98). Indeed, technology is developing so fast that keeping up with this advancement and strategically deciding for or against a technology brings huge benefits if done correctly.

A third challenge identified results from the increased difficulties in monitoring and supervising in the virtual compared to the face-to-face context and the lack of direct feedback when working on tasks (e.g., Blackburn et al., 2003; Driskell et al., 2003; Hertel et al., 2005). Along with that, there is a need for structure and shared norms for collaboration (e.g., Walther & Bunz, 2005). Interaction rules, guidelines, and norms on how to use digital media can enhance interaction and collaboration (Duarte & Snyder, 2011; Kirkman & Stoverink, 2021; Krumm & Schulze, 2017; Swart et al., 2022; Verburg et al., 2013; Walther & Bunz, 2005). This shared understanding can help reduce overcommunication, unpredictable communication patterns, or lack of communication (e.g., Blackburn et al., 2003; Daim et al., 2012; Lee-Kelley & Sankey, 2008). Closely associated with the lack of rules and norms are difficulties in cooperation and coordination (e.g., Aritz et al., 2018; Demirel, 2020; Kanawattanachai & Yoo, 2007; Malhotra et al., 2007). While individual digital skills are an important first step, enabling an entire team to effectively use technologies is pivotal for its effectiveness.

The Leader's Response to Technology-Related Challenges: Leader Digital Competence (LDC)

Based on the challenges posed in the virtual context, we propose that leaders need to integrate new technologies into their work processes and adeptly promote, choose, and use technologies for interaction and leadership (Tuschner et al., 2022). Because of rapid technological advancements, leaders must stay current, effectively engage with technologies, and be confident in their use (Janssen et al., 2013). We define LDC as the leader's ability and inclination to choose, promote, and enable the use of technologies and digital media among their employees. Overall, we perceive leaders as playing a pivotal role in facilitating work in the digital era, and given the challenges outlined above, they can achieve this in three ways.

Digital Interaction Since digital media represent the channels over which leadership and influence is exerted (e.g., Avolio et al., 2014), effective communication via digital media is necessary to clearly communicate goals and distribute responsibilities. Adequate digital media use for communication and navigating a team is therefore among the most critical skills for virtual leaders (Cortellazzo et al., 2019; Tuschner et al., 2022). As described above, it is a matter of using the communication medium in a way that is appropriate to the situation, task, and interaction partner (e.g., Aritz et al., 2018; Fleischmann et al., 2019; Lee & Lee, 2009). Using digital media adequately to lead from afar is pivotal to managing close relationships (see Jawadi et al., 2013); ensure communication efficiency (see Newman et al., 2020), and fulfill employee's needs and expectations (Sivunen, 2008). Skillfully matching digital media to the content, impacts leadership perceptions (e.g., Braun et al., 2019) and can enhance trust in the leader (Norman et al., 2019). Identifying which medium is best suited for virtual interaction and effective communication is an important task for leaders in reducing misunderstandings and conflicts and promoting knowledge sharing and effective collaboration (e.g., Cortellazzo et al., 2019; Daim et al., 2012; Haron et al., 2019).

Taken together, we define *digital interaction* as the leader's ability to interact effectively with employees via digital media (e.g., email, chat or instant messaging, video conferencing, or online collaboration platforms), appropriately selecting the digital medium based on the needs for the respective situation.

Digital Openness The increased need for openness to new technical innovations and the accompanying opportunities of digital technologies also have implications for virtual leaders (Cascio & Montealegre, 2016; Torre & Sarti, 2020). Avolio and colleagues (2000) noted that virtual leaders should employ appropriate technologies and instill a positive attitude among employees toward adopting new technologies. New communication media can support new forms of virtual collaboration to enable quick responses to rapidly changing contexts, such as changing customer needs and novel market developments (Avolio et al., 2000). Due to the continuous development and integration of new technologies, it is vital to enable the use of these new tools. Thus, leaders should stay up-to-date and have an open-minded attitude toward technological developments and digital innovation (Torre & Sarti, 2020; Tuschner et al., 2022). Furthermore, in addition to staying abreast of the newest digital tools, leaders should encourage an open-minded view of novel technologies, thereby fostering technological innovation in the work team (Cortellazzo et al., 2019; Roman et al., 2019). Leaders displaying openness to technological innovation can ultimately enable teams or organizations to fully leverage new technological developments, harness innovation, and increase productivity (Benitez et al., 2022; Cascio & Montealegre, 2016; Peschl & Schüth, 2022).

In conclusion, we define *digital openness* as the leader's open-mindedness and enthusiasm for embracing new technical developments, as well as promoting openness toward and use of new technologies among employees.

Digital Role Modeling According to social learning theory (Bandura, 1969; Sims Jr. & Manz, 1982), leaders can act as coaches and role models, displaying behaviors that encourage employees to adopt digital media in their daily interactions (Sivunen, 2008; Zigurs, 2003). In the virtual context, leaders can have a particularly positive impact on their employees' behaviors by providing guidance for technology use and modeling desired behaviors (e.g., Norman et al., 2019). Direction can be provided, for example, by creating well-functioning structures to facilitate interactions, such as implementing an agreed-upon 24-h response latency, to keep team members' expectations in line (Beranek et al., 2005). This is needed because effective collaboration is essential to virtual team or individual performance (e.g., Haron et al., 2019), team effectiveness (e.g., Morgan et al., 2014), and knowledge sharing (Eisenberg & Krishnan, 2018). Furthermore, leaders' guidance on the meaningful use of digital media is important for high-quality communication among team members (Hambley et al., 2007; Lam, 2016; Zigurs, 2003). Thus, it is the leader's role to enable team members to use digital media adequately and to integrate adequate norms for digital media use within the team (Cortellazzo et al., 2019; Jawadi et al., 2013).

Overall, leaders should provide guidance by acting as a role model and enabling functions and a framework to which team members can adhere. We define *digital role modeling* as the leader's ability to successfully pass on their skills regarding the use of digital media to their employees by

providing support and a well-functioning framework for digital media use.

Nomological Network: LDC in Relation to Existing Leadership Constructs

Convergent Validity: LDC in Relation to Other Constructs Measuring Digital Leadership Competence

In the past, there have been initial attempts to define and measure skills and competencies that are relevant for leaders in the digital age (see Online Supplement 1). While some research has presented constructs of digital leadership skills or competencies, they lack definitions, theoretical foundation, and overall construct clarity. The proposed measures to assess these constructs fall short in their rigorous development and validation, and overall, to the best of our knowledge, no generally accepted measure of digital competence exists. Despite these limitations, we include the proposed digital leadership competence scales by Claassen et al. (2021) and Zeike et al. (2019) to examine their relationship with LDC. The first construct highlights the leader's support in digital work and the employee's ability to participate in digital work-related decisions (Claassen et al., 2021), while the latter focuses on the leader's skills in driving forward and creating enthusiasm regarding digital transformation (Zeike et al., 2019). Since they share a significant overlap regarding the direct focus on the supportive actions displayed by leaders to enable digital work (Claassen et al., 2021) and the future-oriented focus on promoting new technologies (Zeike et al., 2019), we aim to establish convergent validity using the two scales and propose the following:

> ***Hypothesis 1.*** LDC is highly positively related to digital leadership competence measures (i.e., digital leadership and digital transformation).

Discriminant Validity: Similar and Distinct Constructs

In building a nomological network around LDC, we elaborate on how LDC relates to conceptually similar constructs. Building on our literature review, we categorize these constructs into two areas: traditional leadership constructs (i.e., transformational leadership, transactional leadership, and leader-member exchange), and task management constructs (i.e., initiating structure and task orientation). Subsequently, we describe the shared characteristics and divergences that exist between these constructs. Table 1 provides a summary of their similarities and differences to LDC.

First, conceptually linked to LDC but distinct from it are transformational leadership (Carless et al., 2000), transactional leadership (Podsakoff et al., 1990), and leader-member exchange (LMX; Wayne et al., 1997). Even though these leadership styles do not directly address the change in context through digitalization, they belong to the most frequently examined leadership styles in the virtual environment (e.g., Gajendran & Joshi, 2012; Hambley et al., 2007; Hoch & Kozlowski, 2014; Purvanova & Bono, 2009). Additionally, transformational leadership, transactional leadership, and LMX share conceptual overlap with LDC, as they center around a leader's direct influence on employees and the provision of support and resources, ultimately creating the foundation for effectiveness in virtual teams. While transformational leaders contribute to effectiveness by communicating a vision to team members, acting as role models, and offering individual support (Carless et al., 2000), transactional leaders set clear expectations, also employing a system of rewards (Bass, 1985; Podsakoff et al., 1990). LMX theory, on the other hand, posits that leaders establish unique relationships with individual members, providing them with necessary resources and support (Wayne et al., 1997). Despite their similarities, there are notable distinctions between these leadership styles and LDC. First, they do not address *how* leaders create a practical framework and support employees in navigating the digital environment. Moreover, they differ in the structures that leaders design to achieve effectiveness, since LDC directly focuses on using and promoting technologies, including both the current and future use and enablement of technology.

Second, task management constructs incorporate concepts such as initiating structure, planning, clarification, and monitoring to enhance the effectiveness of working on tasks (e.g., Schriesheim et al., 1976; Yukl, 2012). Similarly, LDC underscores the importance of structure, albeit with a specific focus on the use of technology to support employees in completing their tasks. This is because effective management of digital media is crucial for the efficient handling of tasks and interactions (Barley et al., 2011; Verburg et al., 2013). Conceptually, LDC shares similarities with task management, as both concepts emphasize a strong focus on the establishment of structures and boundaries to create an environment conducive to task progress and performance (Yukl, 2012). However, LDC and task management constructs differ. LDC centers around reducing ambiguity and fostering a shared understanding in the context of technology use. In contrast, task management constructs focus on enhancing role and task clarity, by displaying behaviors such as planning, problem-solving, and ensuring quality standards (Brown et al., 2021). We contend that the establishment of structures for effective technology use is a necessary preliminary condition for providing task-related structures in the virtual environment. Thus, without ensuring the effective

Table 1 LDC Compared With Related Constructs

Construct	Definition	Related Construct	LDC	Similarities
Transformational leadership	A transformational leader "(1) communicates a vision, (2) develops staff, (3) provides support, (4) empowers staff, (5) is innovative, (6) leads by example, and (7) is charismatic" (Carless et al., 2000; p. 390)	Focus on motivating their employees to achieve exceptional performance by showing responsivity to individual employee's needs, inspiring and challenging employees	Focus on the digital aspects of employee 's needs; high performance by enabling and promoting technology use	Similarities like acting as a role model, displaying competence and openness regarding new opportunities, and promoting cooperation among team members
Transactional leader behavior / Contingent reward behavior	Defined as a behavior that provides "positive feedback in the form of recognition, praise, acknowledgement, or financial rewards to employees who exhibit desirable behaviors" (Tremblay et al., 2013; p. 233)	Provision, recognition and emphasis of clear structures and expectations by the leader; creation of motivating conditions (by means of a reward system)	Creating conditions in which employees can perform by enabling them and acting as role models even in the virtual context	Focus on fostering and monitoring high performance levels of employees and teams by directly communicating with employees and monitoring processes
Leader-Member Exchange	LMX focuses on individual leader–follower dyads and the differentiation of treatment among employees, resulting in "different quality relationships between the leader and each follower" (Martin et al., 2016, p. 68)	Exchange relationship and quality of relationship between individual employees and their leader; with each employee having an individual relationship quality with their leader	Focus on employees' needs in the context of the (virtual) team; no specific focus on leader-member relationship quality or liking	Focus on the interaction or exchange between employee and leader
Task orientation	Task-oriented leadership behaviors „ensure that people, equipment, and other resources are used in an efficient way to accomplish the mission of a group or organization (Yukl, 2012; p. 69)	Focus on behaviors related to planning, organizing, clarifying responsibilities and expectations, monitoring tasks and progress as well as resolving arising problems that might hinder effectiveness	Focus on the leader 's competencies regarding the actual and future-oriented use of technology besides the provision of resources and structure in the virtual context	The purpose of task-oriented behaviors and LDC is the focus on goal achievement and the efficient and effective accomplishment by providing structure and a guiding framework
Initiating structure	Initiating structure encompasses „whether the leader clearly defines his/her own role and lets followers know what is expected (Schneider & Littrell, 2003, p. 142)	Focus on defining the leader 's own role, expectations and setting out guidelines for performance	Not setting out how a task should be planned and organized, but focusing on creating conditions that make effective planning more likely	Actions by leaders that aim at establishing a functioning structure for interaction and collaboration among team members, with the overall objective of effectiveness

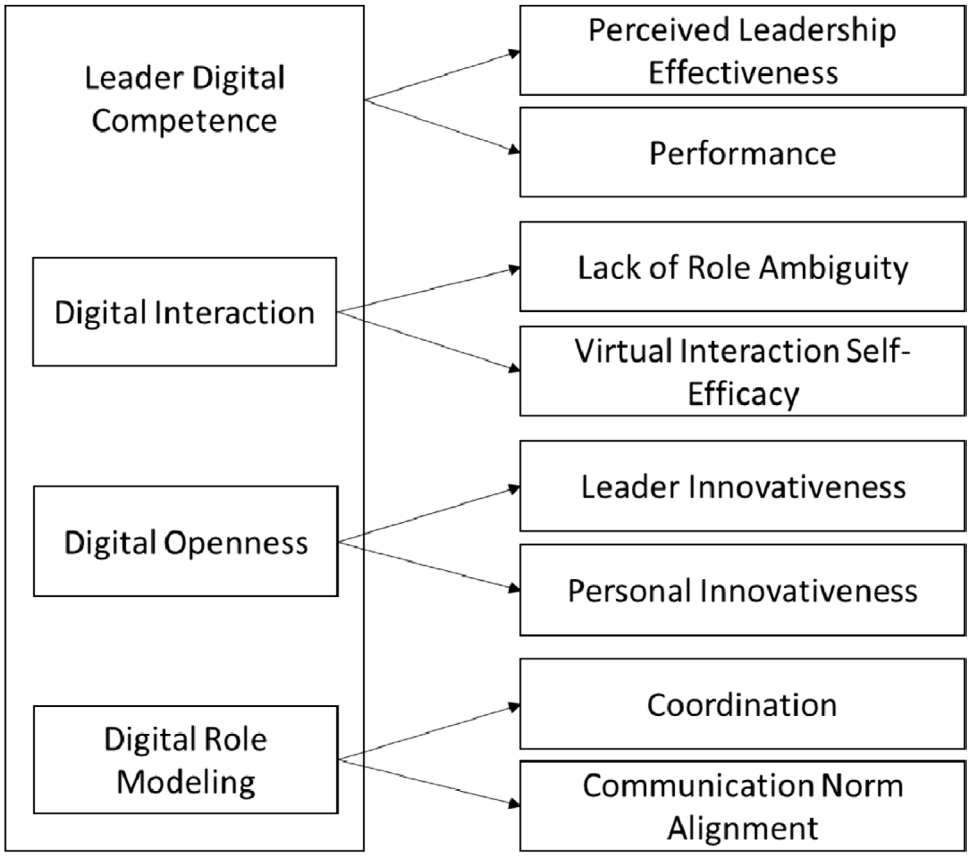

Fig. 1 Hypothesized Model of Leader Digital Competence in Relation to Potential Outcomes (Hypotheses 3a to 4f)

use of technologies, the leader's initiation of structure in the virtual environment may be compromised.

Hypothesis 2a. LDC is positively related to, but empirically distinct from traditional leadership constructs (i.e., transformational leadership, transactional leadership, and LMX).
Hypothesis 2b. LDC is positively related to, but empirically distinct from task management constructs (i.e., initiating structure and task orientation).

Criterion-Related Validity: LDC in Relation to Performance and Leadership Effectiveness

To test the criterion-related validity of LDC, we examined performance and perceived leadership effectiveness as potential outcomes of LDC. The focus is on these two outcomes for initial validation since they reflect important behavioral outcomes and leadership attitudes that directly impact the effectiveness of work in the virtual environment.

One important mechanism that impacts employees' attitudes toward leadership and their performance is social learning (Bandura, 1969). By acting as enablers and serving as role models in dealing with technology (e.g., Blackburn et al., 2003), they support employees in effectively working on their own and interacting with others in the virtual environment. Digitally competent leaders can address the challenges and opportunities of virtual environments (Purvanova & Kenda, 2018) and provide structural support to perform tasks effectively (Hoch & Kozlowski, 2014; Schmidt, 2014). As leaders leverage new technologies to guide employees and facilitate organizational processes (Eberl & Drews, 2021; Zigurs, 2003), we consider LDC a crucial contributor to perceived leadership effectiveness and performance:

Hypothesis 3a. LDC is positively related to perceived leadership effectiveness.
Hypothesis 3b. LDC is positively related to employee performance.

Criterion-Related Validity for the LDC Subscales

As outlined above, the virtual environment presents specific challenges with unique consequences. We expect that the individual dimensions of LDC will be associated with distinct outcomes. It is worth noting that while we held explicit expectations about the hypothesized relationships between a specific LDC dimension and an outcome, we remained open to the possibility that outcomes could also be linked to dimensions beyond those initially

hypothesized. In Fig. 1, we present our hypothesized model, outlining the expected outcomes of LDC and its subdimensions.

Ineffective virtual communication by the leader frequently results in issues such as misunderstandings, limited information sharing, and ambiguity (e.g., Cramton & Orvis, 2003; Griffith et al., 2003; Krumm & Schulze, 2017; Lee-Kelley & Sankey, 2008; Peters & Manz, 2007). This not only compromises a clear understanding of objectives and responsibilities, hindering role clarity (e.g., Kanawattanachai & Yoo, 2007; Lee-Kelley & Sankey, 2008), but also has the potential to negatively influence the employees' confidence in using digital media (Wang & Haggerty, 2011). As the "leader's use of a technology is also expected to impact how it is appropriated by organizational members" (Rains & Bonito, 2017, p. 4), we assume that leaders act as facilitators to promote the development of skills for the appropriate use of technology. Positive virtual interactions, facilitated by leaders, affect employees' self-efficacy through social learning (Bandura, 1969; Staples et al., 1998). Thus, a leader's adequate use and selection of digital media can positively impact their employees' virtual interaction self-efficacy (i.e., the belief in their abilities to interact virtually; Adamovic et al., 2022; Staples et al., 1998; Wang & Haggerty, 2011). Accordingly, we propose the following:

Hypothesis 4a. Digital interaction is positively related to lack of role ambiguity.
Hypothesis 4b. Digital interaction is positively related to employee's virtual interaction self-efficacy.

As continuous technical advancements present new opportunities for technical innovation, embracing digitalization becomes central to exploiting its full potential (Cortellazzo et al., 2019). Being open to new developments is important for experimenting and fostering innovation within organizations (Mewes et al., 2022). In companies, it is the people who drive innovation, and the company's culture, operations, and processes play a pivotal role in nurturing advancements (Kratzer et al., 2017). Leaders who show enthusiasm and encourage openness can cultivate a positive attitude toward innovation (Davis, 1989), inspiring employees to use innovative approaches. Raising awareness about the use, risks and benefits of technologies can foster innovative work behavior (Erhan et al., 2022). Moreover, sharing enthusiasm regarding new digital technologies helps in adopting new tools to improve processes (Cortellazzo et al., 2019). Leaders who act as change initiators in promoting digitalization support employees in adopting new technical developments, thus fostering their personal innovativeness in the domain of information technology (Agarwal & Prasad, 1998; Rogers, 1995).

Hypothesis 4c. Digital openness is positively related to leader innovativeness.
Hypothesis 4d. Digital openness is positively related to employee's personal innovativeness in the domain of technology.

In virtual teams, clear interaction guidelines are needed to accomplish goals, and it is the responsibility of the leader to provide them (e.g., Demirel, 2020; Swart et al., 2022). It is widely acknowledged that rules and guidelines regarding the use of digital media facilitate coordination and collaboration in the team (e.g., Cortellazzo et al., 2019; Jawadi et al., 2013; Schulze & Krumm, 2017). This is primarily because norms have the power to establish a common understanding and regulate actions of team members (Feldman, 1984). By setting an example, leaders display their expectations and provide boundaries that help team collaboration. Thus, leaders who invest in building a shared understanding of the use of digital media, facilitate coordination and the awareness and adherence to virtual communications guidelines (Cortellazzo et al., 2019; Henderson et al., 2016).

Hypothesis 4e. Digital role modeling is positively related to coordination.
Hypothesis 4f. Digital role modeling is positively related to communication norm alignment.

Incremental Validity: LDC and its Added Value Beyond Established Leadership Constructs

Building upon the reasoning in Hypotheses 3a to 4f, we propose that LDC, as a competence that directly affects how leaders enable the use of technology among team members, better explains variance in perceived leadership effectiveness and performance in virtual settings compared to other established leadership constructs (i.e., transformational leadership, transactional leadership, LMX, initiating structure, and task orientation).

Hypotheses 5a and 5b.a and 5b. LDC explains additional variance in a) perceived leadership effectiveness and b) performance beyond established leadership constructs.

Furthermore, we expect the individual dimensions of LDC to be of additional value over established leadership constructs in addressing the challenges and needs in the virtual environment.

Hypotheses 6a and 6b. Digital interaction explains additional variance in a) lack of role ambiguity and b) employee's virtual interaction self-efficacy beyond established leadership constructs.

Hypotheses 6c and 6d. Digital openness explains additional variance in c) leader innovativeness and d) employee's personal innovativeness beyond established leadership constructs.
Hypotheses 6e and 6f. Digital role modeling explains additional variance in e) coordination and f) communication norm alignment beyond established leadership constructs.

Predictive Validity: Work Engagement and Employee Performance

Finally, we expect that LDC will prove valuable in predicting future outcomes relevant to employee performance and engagement. The role of technology choice and selection in the context of virtual team performance has been extensively studied (e.g., Clark et al., 2019; Powell et al., 2004, for a review). As already outlined above, leaders play a pivotal role in encouraging technology use and establishing functional structures that enhance virtual collaboration, ultimately resulting in improved performance outcomes (Demirel, 2020). Furthermore, in virtual teams, work engagement is largely dependent on the team leader's constant effort and the communication media used, supporting the team through its different phases (Panteli et al., 2019). Shaik and Makhecha (2019) found that leaders of global virtual teams encourage their team member's work engagement by establishing a robust virtual infrastructure, utilizing appropriate technology, and ensuring that all team members stay in regular contact. Thus, LDC is thought to strengthen employees' digital work resources and performance over time, and we hypothesize:

Hypothesis 7a. LDC predicts leader ratings of employee performance.
Hypothesis 7b. LDC predicts employee work engagement.

Four independent samples were used to develop and validate the LDC scale empirically. We followed guidelines of Hinkin (1998) for item generation and scale validation. In Study 1, we examined content validity and assessed the factor structure. This was replicated in Study 2, where we also established measurement invariance across languages (German, English, and Mandarin). In Study 3, we established convergent, discriminant, criterion-related, and incremental validity. Finally, in Study 4, we examined predictive validity and correlations between leader and follower ratings. Table 2 displays the steps and analyses used and the associated datasets. Appendix 1, Tables 9 and 10 displays a data transparency table showing the variable overlap between papers that have been published or are under review and the data used in this manuscript as of March 2024.

Study 1: Scale Development, Content Validity, and Factor Analysis

Item Generation

We followed the instruction provided by Hinkin (1998) and deductively developed the items of the LDC scale. That is, we developed definitions of the factors and individual operationalizations (see section *The Leader's Response to Technology-Related Challenges: Leader Digital Competence*) and, drawing on this, we generated items. For reasons grounded in economic considerations and the practicality of application within organizational contexts, we focused on keeping the subscales of LDC short. Therefore, we generated only around four to five items per subscale. Since we focused on relevant digital competencies for leaders from the employee perspective, items are formulated from their viewpoint. We pretested the initial pool of items, followed by using confirmatory factor analysis (CFA) for the primary test of the factor structure of the LDC scale.

Pretest: Content Validity

The resulting item pool was first tested for content validity. We conducted this pretest in a workshop on digital leadership, involving a group of researchers considered experts in the field of leadership. The approach utilized for this pretest was based on the method outlined by Hinkin (1998) and previously employed by MacKenzie and colleagues (1991). We asked 13 researchers to assign the items to the subscales in accordance with the provided definitions. According to this approach, the agreement of an item with the corresponding subscale should be at least 75%. The results revealed that all items on the Digital Openness subscale were correctly assigned, with one exception, achieving an 83% correct classification rate. However, some items within the Digital Interaction and Digital Role Modeling subscales were inaccurately assigned (up to 38%). Subsequent adjustments were made to the items based on these findings. The final set of items is presented in Table 3. A 7-point Likert-type scale was used, ranging from 1 = *completely disagree* to 7 = *completely agree*.

Method

Participants

The invitation link was shared in the authors' networks in Germany. Participation was voluntary and informed consent was obtained from all participants. Data from a total of 243 individuals was collected. A sample of $N = 156$ participants

Table 2 Overview of the Steps Performed in the Four Samples to Develop and Validate the LDC Scale

Sample	Final Sample	Scale Development or Validation Step	Scale Validation Specificity and Variables Used
Study 1	Discussion with $N=13$ researchers for pretesting content validity and $N=156$ German-speaking employees	Development of items reflecting LDC and pretesting the subscales with their respective items; exploratory factor analysis (EFA), dimensionality and reliability	Development and initial validation of a scale consisting of ten items; with five items forming the Digital Interaction, four items forming the Digital Openness, and three items forming the Digital Role Modeling subscale
Study 2	$N=285$ German-speaking employees	Confirmatory factor analysis (CFA), reliability, and measurement invariance across languages	Validation of the three-factor solution consisting of ten items Establishment of measurement invariance (German and English language versions)
Study 3	$N=201$ English-speaking employees	Convergent, discriminant, criterion-related and incremental validity	Examination of convergent (i.e., digital leadership competencies), discriminant (transformational leadership, transactional leadership, LMX, initiating structure and task orientation), criterion-related and incremental validity for the entire LDC scale (i.e., perceived leadership effectiveness and performance) and its subscales (i.e., lack of role ambiguity, virtual interaction self-efficacy, leader innovativeness, personal innovativeness, coordination, and communication norm alignment)
Study 4	$N=452$ Mandarin-speaking team members and 93 team leaders in 93 teams	Predictive validity, measurement invariance across languages	Investigation of predictive validity (i.e., work engagement and employee performance); Establishment of measurement invariance (German and Mandarin language versions)

Table 3 LDC Dimensions with the Respective Items in German, English, and Mandarin

Item	German Original	English Translation	Chinese Translation
Digital Interaction			
Digital Interaction 1	Die Art und Weise, wie meine Führungskraft digitale Medien nutzt, um mit den Mitarbeitern zu kommunizieren, ist angemessen	My leader uses digital media for communicating with his/ her employees in an appropriate way	我的领导以妥当的方式通过数字媒体 (微信、电话、邮件等) 与员工进行沟通。
Digital Interaction 2	Meine Führungskraft sorgt dafür, dass die Kommunikation über digitale Medien im Team sinnvoll geregelt ist.*	My leader ensures that the team has appropriate norms for communication via digital media.*	我的领导确保团队内有恰当的数字媒体沟通规范 (微信群聊规则、邮件沟通规则等) *
Digital Interaction 3	Auch wenn die Führungskraft nicht persönlich anwesend ist, kann sie das Team über digitale Medien führen	Even when my leader is not personally present, he/ she is able to lead the team via digital media	即使我的领导不在现场, 他/她也能够通过数字媒体领导团队。
Digital Interaction 4	Meine Führungskraft weiß, in welcher Situation welches digitale Medium (z.B. Telefon, E-Mail, Chat) am besten geeignet ist	My leader knows which digital medium (e.g., telephone, e-mail, chat) is most appropriate in which situation	我的领导能够根据情境选择恰当的数字沟通媒介 (电话、邮件、微信、视频等)
Digital Interaction 5	Alles in allem funktioniert die digitale Kommunikation mit meiner Führungskraft gut	All in all, digital communication with my leader works well	我的领导与我之间的数字媒体沟通非常有效
Digital Openness			
Digital Openness 1	Meine Führungskraft zeigt Offenheit für neue Technologien	My leader shows openness to new technologies	我的领导对新技术持开放态度。
Digital Openness 2	Meine Führungskraft reagiert begeistert auf technische Innovationen	My leader reacts with enthusiasm when presented with technical innovations	对于技术创新, 我的领导充满热情
Digital Openness 3	Meine Führungskraft fördert Offenheit gegenüber technischen Neuheiten	My leader promotes openness to technical innovations	我的领导提倡技术创新
Digital Openness 4	Meine Führungskraft vermittelt dem Team ihre Begeisterung für neue Technologien.*	My leader shares his/ her enthusiasm for new technologies with the team.*	我的领导将他/她对新技术的热情传递给团队 *
Digital Role Modeling			
Digital Role Modeling 1	Meine Führungskraft ist für mich ein Vorbild hinsichtlich der Nutzung von digitalen Medien	My leader is a role model for me regarding the use of digital media	在使用数字媒体方面, 我的领导是我的榜样。
Digital Role Modeling 2	Meine Führungskraft hilft mir dabei, digitale Medien sinnvoll einzusetzen (z.B. durch Regeln im Umgang mit E-Mails, Absprachen hinsichtlich Erreichbarkeitszeiten, etc.)	My leader helps me use digital media in an appropriate way (e.g., by establishing rules for the use of email, arrangements regarding availability times, etc.)	我的领导帮助我以适当的方式使用数字媒体 (例如, 通过建立使用电子邮件的规则等) 。
Digital Role Modeling 3	Meine Führungskraft schafft den Rahmen dafür, dass ich sinnvoll mit digitalen Medien umgehen kann	My leader creates boundaries so that I can use digital media in an appropriate way	我的领导会创造条件让我以合理的方式使用数字媒体

Items with an asterisk were dropped in the final model

(57.7% female, 42.3% male, $M_{Age} = 41.0$, $SD_{Age} = 17.8$) remained for analyses after excluding data from participants who indicated not having a direct supervisor, communicating with their leader using digital media less than 5% of the time ($n = 76$); excluding data with missing values regarding the LDC scale ($n = 6$), and multivariate outliers as indicated by Mahalanobis distance ($n = 5$). Most participants worked in the communication technology industry ($n = 31$), followed by the public sector ($n = 22$) and the health industry ($n = 21$).

Measures

We initially assessed LDC with the pool of 12 generated items (see again Table 3). Items were presented in German and rated on a scale from 1 = *completely disagree* to 7 = *completely agree*.

Data Analysis

All analyses were performed using R Version 4.1.2. (R Core Team, 2021). Since the LDC scale was developed deductively, based on a priori assumptions regarding a three-dimensional structure, we used CFAs to examine the factor structure (Brown, 2015).[1] To account for non-normality, Satorra-Bentler corrections with the maximum likelihood mean adjusted estimator (MLM) and robust standard errors were applied (Satorra & Bentler, 1994). Model adequacy was assessed using several fit indices, including chi-square, comparative fit index (CFI; Bentler, 1990), Tucker-Lewis index (TLI; Tucker & Lewis, 1973), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR; Hu & Bentler, 1999). An excellent fit is indicated by RMSEA and SRMR values below 0.05, and CFI and TLI values should exceed 0.90 for adequate fit and 0.95 for good fit (Bentler & Bonett, 1980; Hu & Bentler, 1999). Given that the initial CFA indicated a poor fit, the model was modified based on the modification index to improve fit (Whittaker, 2012). Scaled chi-squared difference tests, which are robust to non-normality of data (Satorra & Bentler, 2001), were conducted for model comparisons. Reliability was assessed using Cronbach's alpha (Cronbach, 1951) and McDonald's Omega (ω_{total}, ω_t; McDonald, 1978).

Results

First, a CFA with all 12 items was conducted. Model fit indices indicated a relatively poor model fit for most indicators ($\chi_{Robust}^2 = 132.71$, $df = 51$, $p < 0.001$, $RMSEA_{Robust} = 0.11$, $SRMR = 0.05$, $TLI_{Robust} = 0.93$, $CFI_{Robust} = 0.94$). Furthermore, modification indices suggested cross-loadings concerning the Digital Role Modeling factor with respect to the two items "Digital Interaction 2" and "Digital Openness 4". Upon reviewing these two items and considering their conceptual overlap related to the leader's active role modeling behavior with a strong focus on the team (i.e., establishing communication norms and openness in the team), we decided to gradually remove them. We first removed the item "Digital Interaction 2", however, even after this modification, the model fit was still poor and modification indices suggested remaining concerns related to the item "Digital Openness 4". Therefore, a third CFA was conducted.

Results of the third CFA with only ten items loading on their expected factors indicated excellent fit ($\chi_{Robust}^2 = 50.69$, $df = 32$, $p = 0.019$, $RMSEA_{Robust} = 0.07$, $SRMR = 0.04$, $TLI_{Robust} = 0.98$, $CFI_{Robust} = 0.98$). Model comparisons also highlighted a significantly better fit than the first and second models ($p = 0.003$). In the final model, all items loaded on their respective factor (≥ 0.78). The factors were highly interrelated (Digital Interaction and Digital Openness = 0.70, Digital Interaction and Digital Role Modeling = 0.77, and Digital Openness and Digital Role Modeling = 0.73). The plotted graph for the final model is displayed in Fig. 2. Cronbach's Alpha of the ten-item LDC scale was 0.93, and ω_t was 0.96. Descriptive statistics and the correlation matrix of the LDC items are provided in Table 11 in Appendix 2.

Study 2: Confirmatory Factor Analysis

In Study 2, a second CFA was conducted in another German sample to further support the factor structure of the LDC scale.

Method

Participants

A total of 348 German-speaking participants filled out the online survey. A sample of 309 participants (61.0% female, 37.7% male, $M_{Age} = 32.7$, $SD_{Age} = 17.6$) remained for analyses after the removal of data from 35 participants who indicated not having a direct supervisor, and four further data rows with missing values regarding the focal variables. Most participants held a university degree (69.3%) and worked in consulting ($n = 42$) or in the manufacturing and engineering industry ($n = 31$).

Measures

The revised ten-item LDC scale was administered in German as part of a larger data collection effort.

[1] However, we additionally conducted exploratory factor analyses with principal axis factoring and maximum likelihood analysis, and findings were essentially the same. More specifically, we also found the 10-item model with three factors to fit the data best.

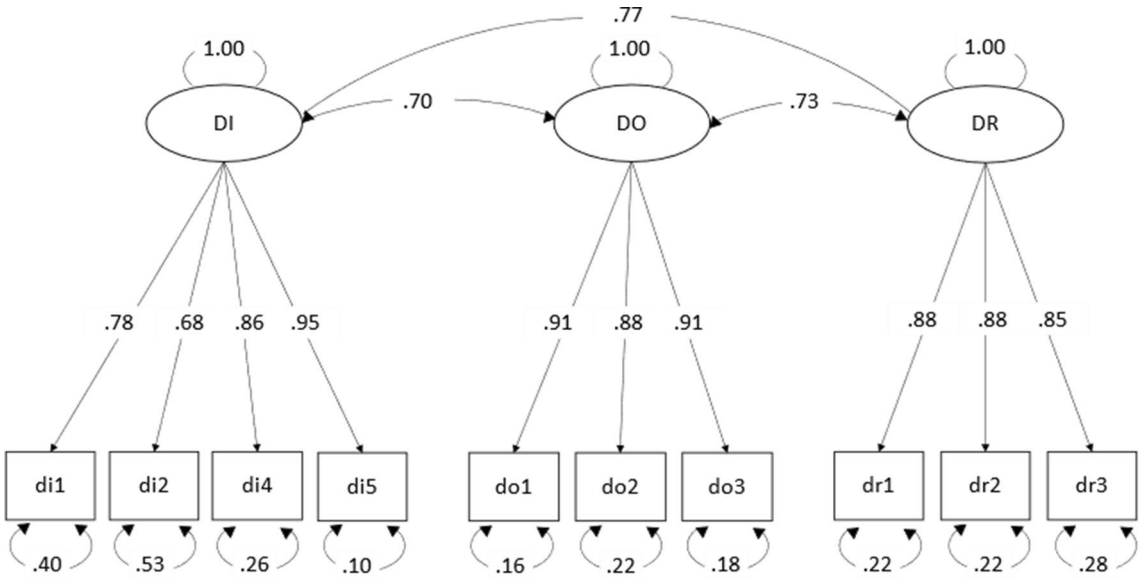

Fig. 2 CFA Model of LDC With Standardized Estimates. Notes. DI = Digital interaction, DO = Digital openness, DR = Digital role modeling

Table 4 Goodness-of-fit Indices for the Five Models Performed

Model	*df*	robust χ^2	robust RMSEA	SRMR	robust CFI	robust TLI
One-factor model	35	415.96	.21	.09	.78	.72
Two-factor (Model 2a)	34	329.63	.19	.08	.83	.77
Two-factor (Model 2b)	34	254.90	.16	.07	.88	.84
Two-factor (Model 2c)	34	257.17	.16	.08	.88	.84
Three-factor model	32	119.26	.10	.05	.95	.93

$N = 309$

Data Analysis

CFAs were conducted using the MLM estimation and the common fit indices as in Study 1. As competing models, we inspected a one-factor solution, three two-factor models (with each two of the three subscales taken together to build a common factor), as well as one first-order three-factor model (with correlated factors). Scaled chi-square difference tests were performed for model comparisons. For internal consistency, Cronbach's α and ω_t are reported.

Results

Confirmatory Factor Analysis

Table 4 shows the fit indices for the conducted CFAs. The results indicated that the one-factor solution (Model 1) and the two-factor solutions, specifically Model 2a (Digital Interaction and Digital Openness items building one common factor, Digital Role Modeling a second factor), Model 2b (Digital Interaction and Digital Role Modeling items building one factor, Digital Openness a second factor), and Model 2c (Digital Openness and Digital Role Modeling building one factor, Digital Interaction a second factor), exhibited poor fit. However, the three-factor model, Model 3, showed a good fit, despite the robust RMSEA value exceeding the recommended threshold[2] of 0.08. Scaled chi-square difference tests revealed that Model 3 provided a better fit to the data compared to Model 1 ($\Delta\chi^2 = 225.87$, $p < 0.001$), as well as compared to Model 2a, 2b, and 2c ($\Delta\chi^2 = 123.68$, $p < 0.001$; $\Delta\chi^2 = 131.30$, $p < 0.001$; and $\Delta\chi^2 = 128.58$, $p < 0.001$, respectively).

The reliability of the LDC scale was high, $\alpha = 0.93$, $\omega_T = 0.95$. For the subscales Digital Interaction, Digital Openness and Digital Role Modeling, Cronbach's alpha values were 0.89, 0.90 and 0.86, and McDonald's omega values were 0.90, 0.90 and 0.87, respectively.

[2] Note, that the RMSEA tends to reject models in relatively small samples (Brown, 2015; Hu & Bentler, 1998). Since the other fit indices indicate good to acceptable fit, and the items all load on their respective factor, the three-factor model is retained.

Study 3: Convergent, Discriminant, Criterion-Related, and Incremental Validity

This study relied on an English-speaking sample and was used to establish measurement invariance, along with convergent, discriminant, criterion-related, and incremental validity.

Method

Participants

For the analyses, data were collected from 204 participants who were recruited via the "Prolific" platform (www.prolific.com). Three data rows were excluded from analyses because they did not meet the criteria for at least one of the two attention checks (e.g., "This is an attention check; if you are reading this, please select 3.") or the integrity check. To participate in the study, participants had to be fluent in English, work at least 20 h per week, have a leader, work in a team, and work remotely at least some of the time. Participants were paid £2 for completing the survey. The average age of the participants was 33.5 ($SD = 8.11$). Among participants, 50% were male, 49% female, and 1% diverse. Most participants worked in either professional, scientific, and technical services ($n = 41$) or financial and insurance services ($n = 29$).

Measures

To translate the LDC scale into English, a back-translation method was employed (Brislin, 1970). Initially, items were translated into English by a native British English speaker. Because of slight discrepancies, subsequently, in a second round, a native US-American English speaker reviewed the items for consistency. For the back-translation process, an independent German native speaker who studied English linguistics conducted the back-translation of the items.

The 10-item LDC scale was assessed alongside the digital leadership competence scale by Claassen et al., 2021 (e.g., "In my department, digital working methods are encouraged"; $\alpha = 0.87$), and three items concerning the leader's vision regarding digital transformation, adapted to the third-person perspective (e.g., "My leader is driving the digital transformation forward proactively in our unit", $\alpha = 0.91$, Zeike et al., 2019). Furthermore, we assessed transformational leadership (e.g.," My leader communicates a clear and positive vision of the future", $\alpha = 0.93$, Carless et al., 2000); transactional leadership behavior (e.g., "My leader always gives me positive feedback when I perform well", $\alpha = 0.93$, Podsakoff et al., 1990); LMX (e.g., "My leader understands my problems and needs", $\alpha = 0.92$, Wayne et al., 1997); initiating structure (e.g., "My leader lets group members know what is expected of them", $\alpha = 0.87$, Schriesheim et al., 1976) and task orientation ($\alpha = 0.96$, Yukl, 2012) as consisting of the four subscales planning (e.g., "My leader develops short-term plans for the work", $\alpha = 0.87$), clarifying (e.g., "My leader clearly explains task assignments and member responsibilities", $\alpha = 0.90$), monitoring ("My leader checks on the progress and quality of the work", $\alpha = 0.87$), and problem solving ("My leader identifies work-related problems that can disrupt operations", $\alpha = 0.89$).

To establish criterion-related validity, employees were asked to rate their performance (e.g., "My team is very productive", $\alpha = 0.95$, Steffens et al., 2014); perceived leadership effectiveness (e.g., "The work of my leader will be very successful in the future", $\alpha = 0.96$, Braun et al., 2019); virtual interaction self-efficacy (e.g., "I am confident about my ability to interact virtually using digital media", $\alpha = 0.89$, adapted from Deng et al., 2004; as based on Spreitzer, 1995); lack of role ambiguity (e.g., "I have clear planned goals and objectives for my job", $\alpha = 0.89$, House, 1971; based on the scale developed by Rizzo et al., 1970). Furthermore, participants assessed their personal innovativeness (adapted to say "technology" instead of "information technology", e.g., "I like to experiment with new technologies", $\alpha = 0.73$, Agarwal & Prasad, 1998); their leader's innovativeness (e.g., "My leader demonstrates originality in his/her work", $\alpha = 0.93$, Basu & Green, 1997); coordination (e.g., "My team avoids duplication of effort", $\alpha = 0.75$, Hoegl et al., 2004), and communication norm alignment (e.g., "My norms of providing feedback are entirely aligned with the other team members", $\alpha = 0.88$, Henderson et al., 2016). Scales were assessed using a response format ranging from 1 = *completely disagree*, to 7 = *completely agree*. Only transformational leadership was assessed on a response format ranging from 1 = *rarely or never* to 5 = *very frequently, if not always*.

Data Analysis

Measurement invariance across languages (see Klotz et al., 2023) was tested using a multi-group CFA with samples from Study 2 (German) and Study 3 (English). We employed MLM estimation and assessed model fit. Configural measurement invariance was examined by specifying separate measurement models for each language version. Subsequently, metric models were specified by constraining the factor loadings for the respective items to be equal (Klotz et al., 2023).

We used the CI_{CFA} technique proposed by Rönkkö and Cho (2022) to establish discriminant validity. Therefore, we estimated CFA models including LDC with its three

factors, along with the related constructs modeled as additional factors. As recommended, the latent variables were scaled by setting their variances to one. Following the guidelines outlined by Rönkkö and Cho (2022), we interpreted the upper limits of the 95% confidence intervals (CI) of the correlations below 0.80 as indicating no issues with discriminant validity. For values ranging between 0.80 and 0.90, there was a marginal concern, albeit suggesting that considering the constructs as distinct was still appropriate (Rönkkö & Cho, 2022). Upper limits between 0.90 and 1 are classified as a moderate concern, and values equal to or above 1 as severe problem. To further establish discriminant validity, we examined competing models containing the related leadership constructs either as separate factors or the same factor as the LDC factors. These models were evaluated using the same fit indices as in Study 1 and Study 2 and compared using scaled chi-square difference tests.

Criterion-related validity was established by examining correlations between the LDC scale, the individual dimensions and theoretically interesting criterion variables. Furthermore, incremental validity was examined by using hierarchical regression analyses, controlling for already existing and validated leadership scales.

Results

Measurement Invariance Across the German-Speaking and English-Speaking Groups

The configural model demonstrated good fit ($\chi_{Robust}^2 = 147.56$, $df = 64$, $p < 0.001$, $RMSEA_{Robust} = 0.08$, $SRMR = 0.04$, $TLI_{Robust} = 0.97$, $CFI_{Robust} = 0.95$). Similarly, the metric model also showed adequate fit ($\chi_{Robust}^2 = 158.42$, $df = 71$, $p < 0.001$, $RMSEA_{Robust} = 0.08$, $SRMR = 0.05$, $TLI_{Robust} = 0.97$, $CFI_{Robust} = 0.96$). The non-significant chi-square difference test ($\Delta\chi^2 = 9.87$, $df = 7$, $p = 0.196$) between the configural and metric models indicates that constraining the factor loadings to be equal across the German and English versions did not substantially alter the model fit, displaying configural and metric invariance.

Convergent Validity

Means, standard deviations, and bivariate correlations are depicted in Table 5. Consistent with Hypotheses 1a and 1b, LDC was highly positively related to the two digital leadership constructs, that are digital leadership ($r = 0.77$, $p < 0.001$) and digital transformation ($r = 0.78$, $p < 0.001$).

Discriminant Validity

Using the CI_{CFA} technique (Rönkkö & Cho, 2022), the upper limits of the 95% CI of the correlations between each transformational leadership, transactional leadership, and LMX with digital interaction, digital openness, and digital role modeling were all below the threshold of 0.80, providing support for discriminant validity. The CI_{CFA} technique was then employed to assess discriminant validity with the four task orientation dimensions (planning, clarifying, monitoring, and problem-solving) as well as the initiating structure scale. While most upper limits of the 95% CI correlations fell below 0.80, correlations of the factors clarifying, monitoring, and initiating structure with the factor digital role modeling fell between 0.80 and 0.81. Additionally, the correlation between digital interaction and initiating structure was 0.82, indicating potential marginal problems, although still suggesting a distinction between the constructs.

Finally, we conducted four CFAs. In the first model, Model 1a, traditional leadership constructs (e.g., transformational leadership, transactional leadership, and LMX) and the LDC subscales were included as individual factors, resulting in a six-factor solution. The fit of Model 1a was good, $\chi_{Robust}^2 = 488.86$, $df = 362$, $RMSEA_{Robust} = 0.05$, $SRMR = 0.05$, $CFI_{Robust} = 0.96$, and $TLI_{Robust} = 0.96$. Model 1b, representing a one-factor solution, showed a poor fit, $\chi_{Robust}^2 = 1342.98$, $df = 377$, $RMSEA_{Robust} = 0.14$, $SRMR = 0.09$, $CFI_{Robust} = 0.70$, and $TLI_{Robust} = 0.68$. In Model 2a, the task management constructs were included, with initiating structure, planning, clarifying, monitoring, problem-solving, and the LDC subscales each represented as one factor. The model fit of Model 2a was excellent, $\chi_{Robust}^2 = 610.00$, $df = 467$, $RMSEA_{Robust} = 0.05$, $SRMR = 0.05$, $CFI_{Robust} = 0.95$, and $TLI_{Robust} = 0.95$. Finally, Model 2b was modeled as a one-factor solution with all items of LDC, initiating structure and task orientation loading on one general factor. The model fit indices revealed a poor fit, $\chi_{Robust}^2 = 1232.93$, $df = 495$, $RMSEA_{Robust} = 0.11$, $SRMR = 0.08$, $CFI_{Robust} = 0.76$, and $TLI_{Robust} = 0.74$. Additionally, all scaled chi-square difference tests indicated that the models with distinct factors had a better fit ($p < 0.001$).

Criterion-Related Validity

The overall LDC scale showed significant positive correlations with perceived leadership effectiveness ($r = 0.73$, $p < 0.001$) and performance ($r = 0.62$, $p < 0.001$), supporting Hypotheses 3a and 3b. Additionally, digital interaction was positively correlated with its expected criterion variables (i.e., lack of role ambiguity, $r = 0.47$, $p < 0.001$, and virtual interaction self-efficacy, $r = 0.43$, $p < 0.001$). Similarly, digital openness was positively associated with

Table 5 Means, Standard Deviations, and Bivariate Correlations

Variable	*M*	*SD*	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
(1) LDC	5.72	1.00																		
(2) Digital interaction	6.09	1.03	.87																	
(3) Digital openness	5.90	1.18	.86	.66																
(4) DRM	5.05	1.33	.85	.57	.61															
(5) DL	5.47	0.97	.77	.63	.71	.64														
(6) DT	5.25	1.30	.78	.58	.75	.68	.77													
(7) TAL	5.19	1.41	.57	.43	.50	.55	.62	.56												
(8) TFL	3.81	0.89	.71	.55	.65	.63	.68	.66	.73											
(9) LMX	5.23	1.16	.60	.51	.55	.50	.60	.55	.65	.81										
(10) IS	5.57	0.87	.69	.63	.58	.58	.62	.62	.56	.68	.57									
(11) Task orientation	5.32	1.17	.73	.59	.62	.66	.64	.66	.60	.80	.70	.82								
(12) PLE	5.47	1.39	.73	.60	.63	.65	.63	.63	.69	.90	.82	.70	.81							
(13) Performance	5.83	1.01	.62	.54	.56	.50	.61	.55	.46	.55	.50	.55	.55	.60						
(14) LRA	5.73	0.92	.53	.47	.42	.48	.57	.44	.50	.55	.47	.55	.56	.54	.65					
(15) VISE	6.19	0.83	.36	.43	.37	.14	.44	.33	.27	.28	.23	.33	.27	.28	.50	.46				
(16) LI	4.97	1.39	.66	.49	.62	.60	.62	.68	.61	.76	.66	.64	.75	.74	.52	.43	.21			
(17) PI	5.41	1.05	.14	.09	.22	.08	.20	.23	.11	.05	.04	.12	.12	.07	.27	.32	.41	.08		
(18) Coordination	5.14	1.00	.47	.36	.40	.46	.47	.47	.36	.48	.40	.52	.52	.44	.58	.49	.26	.38	.13	
(19) CNA	5.36	0.99	.56	.50	.48	.47	.55	.54	.39	.51	.46	.47	.53	.50	.59	.56	.33	.47	.14	.54

LDC = Leader digital competence, DL = Digital leadership; DT = Digital transformation; TAL = Transactional leadership, TFL = Transformational leadership, LMX = Leader-member exchange, IS = Initiating structure, PLE = Perceived leadership effectiveness, LRA = Lack of role ambiguity, VISE = Virtual interaction self-efficacy, LI = Leader innovativeness, PI = Personal innovativeness, CNA = Communication norm alignment

All correlation coefficients above .14 are significant at $p < .05$; all correlation coefficients equal to or above .23 are significant at $p < .001$

leader innovativeness ($r = 0.62$, $p < 0.001$) and personal innovativeness ($r = 0.22$, $p = 0.002$), while digital role modeling was positively associated with coordination ($r = 0.46$, $p < 0.001$) and communication norm alignment ($r = 0.47$, $p < 0.001$). Hence, Hypotheses 4a to 4f were supported.

Incremental Validity

The results of the hierarchical regression analyses are presented in Table 6. To assess the incremental validity of the LDC scale, perceived leadership effectiveness and performance were initially predicted by established leadership constructs (i.e., transformational leadership, transactional leadership, LMX, initiating structure, and task orientation). Subsequently, LDC was entered into the model. LDC predicted additional variance in perceived leadership effectiveness ($\beta = 0.11$, $p = 0.014$) and performance ($\beta = 0.38$, $p < 0.001$) when controlling for the other leadership constructs, thus supporting Hypotheses 5a and 5b.

Hypotheses 6a to 6f posited that individual subscales would explain additional variance beyond other established leadership constructs. Regarding lack of role ambiguity, digital role modeling was only marginally significant ($\beta = 0.15$, $p = 0.077$) when controlling for the other LDC subscales and established leadership constructs. Additionally, supporting our hypotheses, higher ratings of leader digital interaction were associated with higher ratings of virtual interaction self-efficacy ($\beta = 0.37$, $p < 0.001$). Regarding digital openness and its incremental validity, digital openness was significantly related to leader innovativeness ($\beta = 0.17$, $p = 0.011$) and personal innovativeness ($\beta = 0.35$, $p < 0.001$) when controlling for the remaining leadership constructs. Finally, digital role modeling was positively associated with coordination ($\beta = 0.18$, $p = 0.045$) but not with communication norm alignment ($\beta = 0.10$, $p = 0.225$) when controlling for the other variables. Overall, the analyses provided support for Hypotheses 6b to 6e, while rejecting Hypotheses 6a and 6f.

Study 4: Predictive Validity

Finally, in this study, we examined the predictive power of LDC in a Chinese sample.

Table 6 Hierarchical Regressions for Incremental Validity of LDC and its Subscales

Variable	Step 1		Step 2		Step 1		Step 2	
	Perceived Leadership Effectiveness		Perceived Leadership Effectiveness		Performance		Performance	
	β	*p*	β	*p*	β	*p*	β	*p*
TFL	.50	< .001	.47	< .001	.18	.168	.08	.528
TAL	.02	.651	.01	.779	.06	.467	.04	.654
LMX	.24	< .001	.24	< .001	.12	.229	.11	.256
Initiating structure	.06	.255	.03	.582	.28	.006	.18	.068
Task orientation	.19	.002	.16	.007	.06	.646	-.03	.772
LDC			.11	.014			.38	< .001
R^2 (Adj. R^2)	.85 (.85)		.85 (.85)		.37 (.35)		.43 (.41)	
ΔR^2			.01				.06	
Variable	Step 1		Step 2		Step 1		Step 2	
	Lack of Role Ambiguity		Lack of Role Ambiguity		Virtual Interaction Self-Efficacy		Virtual Interaction Self-Efficacy	
	β	*p*	β	*p*	β	*p*	β	*p*
TFL	.13	.300	.12	.355	.08	.599	.05	.740
TAL	.17	.046	.16	.061	.10	.302	.16	.094
LMX	.02	.873	.00	.969	-.01	.964	-.11	.331
Initiating structure	.25	.013	.19	.068	.29	.014	.12	.294
Task orientation	.14	.266	.10	.441	-.09	.532	-.04	.800
Digital interaction			.15	.077			.37	< .001
Digital openness			-.06	.493			.21	.026
Digital role modeling			.09	.298			-.31	.001
R^2 (Adj. R^2)	.38 (.36)		.39 (.37)		.12 (.10)		.25 (.22)	
ΔR^2			.02				.13	
Variable	Step 1		Step 2		Step 1		Step 2	
	Leader Innovativeness		Leader Innovativeness		Personal Innovativeness		Personal Innovativeness	
	β	*p*	β	*p*	β	*p*	β	*p*
TFL	.33	< .001	.26	.009	-.20	.194	-.31	.054
TAL	.09	.157	.07	.278	.15	.161	.15	.157
LMX	.07	.356	.09	.240	-.05	.691	-.05	.659
Initiating structure	.06	.436	.06	.443	.05	.681	.03	.797
Task orientation	.33	< .001	.28	.003	.19	.210	.18	.237
Digital interaction			-.09	.165			-.09	.357
Digital openness			.17	.011			.35	< .001
Digital role modeling			.09	.174			-.08	.437
R^2 (Adj. R^2)	.64 (.63)		.65 (.64)		.03 (.01)		.09 (.05)	
ΔR^2			.02				.05	
Variable	Step 1		Step 2		Step 1		Step 2	
	Coordination		Coordination		Communication norm alignment		Communication norm alignment	
	β	*p*	β	*p*	β	*p*	β	*p*
TFL	.18	.171	.13	.346	.15	.260	.07	.580
TAL	-.03	.766	-.06	.510	-.00	.982	-.02	.840
LMX	-.01	.889	.02	.884	.11	.305	.09	.405
Initiating structure	.29	.006	.30	.007	.10	.325	-.00	.993
Task orientation	.16	.200	.10	.464	.25	.049	.18	.158
Digital interaction			-.07	.452			.19	.030

Table 6 (continued)

Digital openness			.04	.641		.10	.265	
Digital role modeling			.18	.045		.10	.225	
R^2 (Adj. R^2)	.31 (.29)		.33 (.30)		.31 (.29)	.36 (.33)		
ΔR^2			.02			.05		

TFL = Transformational leadership, TAL = Transactional leadership, LMX = Leader-member exchange, LDC = Leader digital competence

Method

Participants

In this sample, participants were team members and leaders from a Chinese organization in the banking industry. Respondents were incentivized with 70 Yuan (approximately US $10) upon completion of the first and second part of the survey. Informed consent was obtained from all participants. A total of 479 team members, grouped into 98 teams, completed the questionnaire at the first measurement point. About four weeks later, 93 team leaders and their 454 team members completed the survey at the second measurement point. After excluding data from two participants with missing values, a total of 93 team leaders (37.6% female, 62.3% male) and 452 team members (42.3% female, 57.7% male) grouped into 93 teams were included in the data analyses. The average number of participants per team was 4.9 ($SD = 1.0$). Team members were on average 32.8 years ($SD = 9.4$) old, while leaders had an average age of 32.5 years ($SD = 8.7$). The majority of leaders held a university degree (90.3%), whereas only 56.9% of team members held a university degree.

Measures

All items, if not already available in English, were translated from German into English and then from English into Mandarin using back translation (Brislin, 1970, 1986). For the Chinese version of the LDC scale, items were first translated into Mandarin by a bilingual research assistant (a Ph.D. student of organizational behavior). Subsequently, another doctoral student of organizational behavior translated the items back into English. Any discrepancies between the original and back-translated versions were collaboratively corrected. In cases of discrepancies, the back-translation process was repeated until no noticeable differences remained between the two versions.

At the first measurement point, employees rated LDC, and at the second measurement point, they rated their work engagement (Schaufeli et al., 2006; "At my work, we feel bursting with energy"). Team leaders provided self-reports on LDC at the first measurement point and individual performance ratings for every employee at the second measurement point (Lam et al., 2002; e.g., "This employee is very competent"). Both LDC and employee performance were rated on a response format ranging from 1 = *strongly disagree* to 6 = *strongly agree*, while work engagement was rated on a scale from 1 = *never* to 6 = *always*.

Data Analysis

First, as in Study 3, measurement invariance across languages was tested using a multi-group CFA with the German-speaking sample from Study 2 and the Mandarin-speaking sample from Study 4. Next, predictive validity was examined using bivariate correlations and multilevel regression analyses, with work engagement and individual performance being predicted by LDC at level 1. To examine the justification of aggregating subordinates' reports on LDC to the team level in the Chinese sample, we calculated ICC(1), ICC(2), and r_{wg} (Dixon & Cunningham, 2006). We used the threshold of 0.70 for r_{wg} (Klein et al., 2000) and for ICC(2) to justify aggregation (Bliese et al., 2002). Since ICC(2) values of LDC were below the recommended threshold, LDC ratings were not aggregated to the team level, and multilevel models with random intercepts with LDC on the first level were calculated using the *lme4* package in R. Predictor variables were mean-centered.

Results

Measurement Invariance Across the German-Speaking and Mandarin-Speaking Groups

The configural model, including the German and Chinese groups, showed a good model fit ($\chi_{Robust}^2 = 186.14$, $df = 64$, $p < 0.001$, $RMSEA_{Robust} = 0.08$, $SRMR = 0.04$, $TLI_{Robust} = 0.96$, $CFI_{Robust} = 0.95$). The metric model also had an adequate model fit ($\chi_{Robust}^2 = 195.25$, $df = 71$, $p < 0.001$, $RMSEA_{Robust} = 0.08$, $SRMR = 0.04$, $TLI_{Robust} = 0.96$, $CFI_{Robust} = 0.96$). The chi-square difference test comparing the configural and metric models was not significant, $\Delta\chi^2 = 4.75$, $df = 7$, $p = 0.690$, indicating that the model fit did not substantially change after constraining the factor loadings to be equal across the German and Chinese

Table 7 Means, Standard Deviations and Bivariate correlations of Employee's and Leader's Evaluations

Measures	M	SD	α	(1)	(2)	(3)
(1) LDC (employee rating at T1)	4.71	0.81	.92			
(2) LDC (leader rating at T1)	4.75	0.69	.91	.35***		
(3) Work engagement (employee rating at T2)	4.56	0.83	.98	.14**	.02	
(4) Employee performance (leader rating at T2)	4.07	1.05	.88	.19***	.11**	.12***

$N = 452$. LDC = leader digital competence; T = time

***$p < .001$, **$p < .01$

Table 8 Predictive Validity using Multilevel Regression Analyses

Employee performance and work engagement predicted by LDC rated by employees												
	Performance						Work engagement					
Variables		Model 1			Model 2			Model 1			Model 2	
	B	SE	*p*	B	SE	*p*	B	SE	*p*	B	SE	*p*
	Fixed effects											
Intercept	4.07	0.06	< .001	4.07	0.06	< .001	4.56	0.05	< .001	4.56	0.05	< .001
LDC rated by employees				0.25	0.06	< .001				0.15	0.05	.002
	Random effects											
$\sigma^2_{\gamma 0}$	0.18			0.17			0.11			0.11		
σ^2_{ϵ}	0.93			0.90			0.59			0.59		
Employee performance and work engagement predicted by LDC rated by leaders												
	Performance						Work engagement					
Variables		Model 1			Model 2			Model 1			Model 2	
	B	SE	*p*	B	SE	*p*	B	SE	*p*	B	SE	*p*
	Fixed effects											
Intercept	4.07	0.06	< .001	4.07	0.06	< .001	4.56	0.05	< .001	4.56	0.05	< .001
LDC rated by leaders				0.17	0.09	.052				0.02	0.07	.770
	Random effects											
$\sigma^2_{\gamma 0}$	0.18			0.16			0.11			0.11		
σ^2_{ϵ}	0.93			0.93			0.59			0.59		

LDC = leader digital competence

versions. Therefore, configural and metric invariance were established.

Predictive Validity

Means, standard deviations, and bivariate correlations are displayed in Table 7. Correlations on the individual level in the Chinese sample indicate that LDC, as evaluated by employees, was positively related to work engagement at Time 2, $r = 0.14$, $p = 0.003$, and employee performance rated by the leader at Time 2 ($r = 0.19$, $p < 0.001$).

Next, random intercept models with fixed slopes were conducted (see Table 8). We inspected whether LDC, as rated by employees at Time 1, predicted work engagement and employee performance at Time 2. We first established an intercept-only model (M1), followed by a random intercept model with LDC entered (M2). The results show that LDC rated by employees significantly predicted work engagement (B = 0.15, $p = 0.002$). Furthermore, employee's ratings of LDC significantly predicted employee performance evaluations indicated by their leaders (B = 0.25, $p < 0.001$). For exploratory purposes, we examined whether self-reported LDC by the leaders predicted employee performance or work engagement. LDC rated by the leader did not significantly predict work engagement, B = 0.02, $p = 0.770$, or performance ratings, B = 0.17, $p = 0.052$.

General Discussion

Virtuality is a highly prominent work context today (Contreras et al., 2020), and the question of which competencies leaders need to possess to be effective in this emerging environment is of great interest for both practitioners and researchers (Contreras et al., 2020; Cortellazzo et al.,

2019). Therefore, in the present article, our primary objective was to develop and validate a scale to capture digital competencies important for virtual leaders. We built upon theoretical and empirical work that centers around changes in the workplace prompted by digitalization and the enabling role that leaders play in this context. We conceptualized LDC as the leader's competencies in choosing, promoting, and enabling digital media and technologies among employees. Analyses supported the underlying factor structure including three correlating factors and their measurement invariance across three languages. Our assumptions regarding its nomological network (Hypotheses 1, 2a, and 2b), its criterion-related validity (Hypotheses 3a and 3b and Hypotheses 4a to 4f, for the subscales), and predictive validity (Hypotheses 7a and 7b) were supported. Moreover, we demonstrate that LDC and its subscales have incremental validity for some proposed criteria over established leadership constructs, supporting Hypotheses 5a and 5b and 6b to 6e. However, against expectations, digital interaction only explained a marginal amount of variance in lack of role ambiguity beyond other leadership constructs (Hypothesis 6a) and digital role modeling was not significantly related to communication norm alignment when controlling for other leadership constructs (Hypothesis 6f). Nevertheless, our findings underline the utility of LDC and highlight that it is in the leader's hands to create the foundation for effectiveness in the virtual environment (Brown et al., 2021).

Theoretical Contributions

We introduce LDC as a new construct that contributes central insights to our comprehension of leadership effectiveness in the virtual environment. This research adds to the literature by addressing the need for a more systematic examination of leadership competencies in the digital era (Eberl & Drews, 2021), impeded by a lack of a psychometrically sound measurement instrument. Drawing on more modern theoretical frameworks that suggest that technologies do not have uniform effects on outcomes, but that their influence is shaped by the characteristics of users and/or situations (e.g., Carlson & Zmud, 1999; Landers & Marin, 2021; Spears et al., 2007), we argue that it is time to closely consider the leader's use and promotion of technologies in research. Therefore, LDC provides a foundation for further exploring the interplay between leadership and technology adoption over time (Larson & deChurch, 2020).

There are four main conclusions to derive from the present studies. First, LDC represents a multidimensional construct, including three highly interrelated competencies to address the challenges and needs of the virtual environment. These three dimensions suggest that virtual leaders should: (a) use digital media proficiently when interacting with employees (Digital Interaction), (b) show openness and promote enthusiasm for new technical innovations (Digital Openness), and (c) act as a role model to enable employees to collaborate via digital media (Digital Role Modeling).

Second, we offer a conceptual model of LDC that is embedded within a nomological network. The high correlations with two digital leadership scales developed by practitioners and experts in the field (Claassen et al., 2021; Zeike et al., 2019) underscore its practicality and utility in organizational settings. Furthermore, our findings indicate that LDC is associated with, yet distinct from, similar traditional leadership and task management constructs. Notably, the overlap with task orientation and initiating structure underscores the scales' shared emphasis on providing structure (Yukl, 2012). However, in the context of LDC, the ambiguity resulting from virtuality is reduced not by clarifying and monitoring task progress but by the leader's ability to enable the use of technologies and facilitate virtual work. Within the nomological network, LDC also shows discriminant validity against leadership constructs initially presented in the more traditional face-to-face context (i.e., transformational leadership, transactional leadership, and LMX). This underscores the assumption that, even though LDC shares significant similarities with traditional leadership constructs due to their focus on leader–follower interactions and the provision of support to achieve high performance, it nevertheless differs due to the different sources of support digitally competent leaders provide.

Third, we demonstrate that the LDC scale and its subscales explain a significant amount of variance in expected criteria, which resemble outcomes specific to the virtual context and the use of technologies (e.g., employees' virtual interaction self-efficacy or personal innovativeness in the domain of technology). This is in addition to more general attitudes and behaviors of employees (e.g., performance, perceived leadership effectiveness, or lack of role ambiguity). We also demonstrate that LDC has incremental validity for central outcomes over established and popular leadership constructs, undermining the assumption that, even though the compared leadership constructs are essential to success in virtual contexts (Cortellazzo et al., 2019; Kayworth & Leidner, 2002; Purvanova & Bono, 2009), LDC serves as an additional and unique contributor to leadership effectiveness. By examining the contribution of the single dimensions of LDC and showing that they differentially predict certain outcomes, the present research provides insights into the distinct roles of the subscales of LDC in addressing virtuality-related challenges and needs. Taken together, we provide a foundation for further examination of digital

competencies that leaders should possess to navigate their employees through the virtual context.

Practical Implications

As many leaders today report not being sufficiently equipped to confidently lead in the virtual context (Development Dimensions International Inc., 2021), we view it as essential to provide practitioners with evidence on how leaders can influence employees effectively in the face of virtuality. We argue that it is insufficient for leaders to concentrate solely on acquiring the knowledge and skills for using a specific digital medium. Instead, truly digitally competent leaders go further by establishing adequate conditions for employees, fostering enthusiasm for new technologies, and implementing structures that employees can rely on. LDC is a practical and hands-on construct that displays central competencies for leaders to fully leverage the increased reliance on technologies. In this context, the framework around LDC developed in the present article can help practitioners focus on the most relevant actions when designing development measures for virtual leaders.

Limitations and Future Directions

Despite the strengths of the present studies, there are some limitations that should be mentioned and open questions that need to be addressed in future research. First, only Study 4 contained data with a temporal delay between two measurement points and two sources (i.e., employee and leader ratings). The cross-sectional design and reliance on a common source and method hinder the drawing of robust conclusions about the impact of LDC on outcomes in Study 3. Moreover, since LDC was not experimentally manipulated in the present studies, no conclusions regarding causality can be drawn. Even though it is unlikely that some of the presented constructs are causal antecedents of LDC (e.g., LDC is unlikely to be a consequence of coordination or role ambiguity), this is possible for other relationships (e.g., LDC could be predicted by leader innovativeness). Future research should, therefore, focus on a more longitudinal examination of LDC, not only considering further outcomes (e.g., health-related outcomes or organizational outcomes) but also potential antecedents that have an impact on LDC. In this context, it would be especially fruitful to examine leader characteristics (e.g., technology or digital media self-efficacy beliefs, previous experience with digital media, or age) that impact the development of LDC.

Second, employees' LDC ratings might be distorted by assumed similarity to the leader or other rater biases (Lee et al., 2009). Although the approach of assessing employees' evaluations of leaders' competencies is common in previous research (e.g., Claassen et al., 2021; Roman et al., 2019), employees may be unaware of leaders' actual knowledge, for instance, regarding the benefits and differences that various digital media bring (Shachaf & Hara, 2007). However, we opted for this approach to assess LDC, as our goal was to focus on competencies for leaders that are directly tangible to employees. Study 4 displays significant correlations between leaders' self-reports and employees' ratings of LDC. However, leaders' self-reported LDC did not significantly predict employee outcomes. This finding highlights the notion that the employee's perception of adequate technology use and promotion by their leaders shapes their beliefs, attitudes, and behaviors (e.g., Liao, 2017; Newman et al., 2020).

Third, we examined only the direct impact of LDC on outcomes in the present studies. Earlier research questions whether the same leadership behaviors and styles are equally effective in the virtual environment and in the more traditional face-to-face context (Schmidt, 2014). While some studies show that specific leadership styles become more important in the virtual context (e.g., transformational leadership having less impact in the presence of higher virtuality levels; Hoch & Kozlowski, 2014), the opposite has been found in others (e.g., Purvanova & Bono, 2009). Therefore, further explanation needs to be offered regarding the conditions under which LDC might be a particularly required success factor in virtual teams. In this context, one area of future research could be the empirical investigation of employee characteristics (e.g., employees' past experiences or exposure to digital media) or contextual factors (e.g., higher degrees of ambiguity, higher levels of virtuality, larger teams) that might make it more critical for leaders to provide structure and direction in enabling and promoting technologies (e.g., Hambley et al., 2007; Kayworth & Leidner, 2002). Examining this situational dependence could help us better understand the contextual factors that might make LDC particularly conducive to performance.

Conclusions

This research presents the development and validation of the LDC scale to measure leaders' competencies in using, promoting, and enabling digital media and technologies. The scale reflects a short scale with satisfactory psychometric properties, validated in three languages (German, English, and Mandarin). Although more research is needed to replicate the findings, we believe the LDC scale serves as a good starting point to advance research on virtual leadership. Furthermore, the present research may provide organizational practices with a framework and tool to assess development needs and evaluate training activities to prepare leaders for the digital era.

Appendix 1

Table 9 Data Transparency Table of the Dataset (Study 1)

Variable	Manuscript 1 (Current Manuscript)	Manuscript 2 (Conference Paper)	Manuscript 3 (Work in Progress)
Leader Digital Competence	X		
Self-Leadership-Culture		X	X
Work Engagement		X	
Job Satisfaction		X	

In Manuscripts 2 and 3, the goal is to develop a scale to measure self-leadership culture in organizations. These scales are not part of the current manuscript. Note that the variable overlap between Study 1 in the current manuscript and Manuscript 3 is reflective of its status as of March 2024

Table 10 Data Transparency Table of the Dataset (Study 4)

Variable	Manuscript 1 (Current Manuscript)	Manuscript 4 (Published Article)
Follower-Rated Leader Phubbing T1		X
Follower-Rated Leader Digital Competence T1	X	
Follower-Rated Supervisor Support T1		X
Follower-Rated Work Engagement T2	X	X
Leader-Rated Leader Digital Competence T1	X	
Leader-Rated Follower Performance T2	X	X

T = time. In Manuscript 4, the focus of the study is to investigate how leaders' (smart)phone use at work relates to follower work engagement and performance, and if this relationship is mediated by perceived leader support. The variable overlap of Study 4 in the current manuscript with Manuscript 4 is reflective of its status as of March 2024

Appendix 2

Table 11 Means, Standard Deviations and Pearson Correlations of the Resulting ten Items (Study 1)

Variable	M	SD	digint1	digint3	digint4	digint5	digop1	digop2	digop3	digrm1	digrm2
digint1	5.40	1.30									
digint3	4.94	1.65	.50								
digint4	5.02	1.68	.68	.58							
digint5	5.35	1.38	.75	.66	.81						
digop1	5.71	1.46	.48	.35	.61	.63					
digop2	5.07	1.59	.36	.36	.51	.53	.81				
digop3	5.46	1.48	.50	.43	.61	.61	.83	.80			
digrm1	3.72	1.80	.52	.49	.61	.62	.61	.64	.61		
digrm2	3.94	1.84	.46	.52	.57	.62	.53	.56	.54	.79	
digrm3	4.33	1.91	.50	.51	.60	.66	.57	.52	.58	.72	.76

Digint = Digital interaction, Digop = Digital openness, Digrm = Digital role modeling

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Data Availability This article is based on four datasets. The dataset from Study 1 was previously utilized in a conference paper and is currently being used in a manuscript in progress. Additionally, the dataset from Study 4 was utilized in a published article. The variable overlap is outlined in the appendix. The datasets generated and analyzed during the current study are available from the first author on reasonable request (Helen op 't Roodt, Email: helen.optroodt@gmail.com).

Declarations Ethical approval was granted for the dataset of Study 4 by Renmin University of China. Ethical approval by the Ethics Committee of the Goethe University Frankfurt was not required for the datasets of Study 1 to 3. Informed consent was obtained from all individual participants included in the study.

Consent to Publish Not applicable. No identifying information about participants is available in the article.

Competing Interest The authors declare that they have no conflict of interest.

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