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Design thinking in physical and virtual environments: Conceptual foundations, qualitative analysis, and practical implications

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ABSTRACT

Design thinking (DT) is a widely-used innovation approach characterized by its experience-based character. It revolves around creating innovative solutions through extensive interaction among end-users, team members, and other stakeholders. However, traditional on-site, physical DT sessions are increasingly replaced by virtual sessions, potentially undermining the experiential nature of DT. This study examines the effects of changing from a physical to a virtual format on participants' experiences in DT processes as well as the resulting outcomes. To this end, we first identified two established complementary psychological theories—construal level theory and embodied cognition—that provide starting points for understanding the experiences of participants in physical and virtual DT formats. Next, we pursued an exploratory qualitative study by conducting 41 in-depth interviews with DT experts from research and practice. Our findings show that the DT format has profound effects across all phases of the DT process. From a theoretical perspective, we contribute by showing that changing the DT format to a virtual setting affects participants' cognitive experiences during all DT process phases and the respective outcomes. From a managerial perspective, we suggest a roadmap for designing a hybrid DT process that integrates the advantages of both physical and virtual DT formats.

1. Introduction

Design thinking (DT) is a widely utilized approach for structuring innovation processes in the development of products and services (Brown, 2008; Brown and Katz, 2011; Wang, 2022). One of the key characteristics of the DT approach is its experience-based character: Each step in the DT process relies on repeated, personal interactions between end-users, stakeholders, and DT team members (Kolko, 2015). To allow for such interactions, DT workshops are typically conducted in on-site environments such as design studios, innovation labs, or natural user habitats (Plattner et al., 2011). Owing to this human-centered approach to innovation, DT has proven particularly effective for tackling "wicked problems", that is, innovation challenges characterized by significant uncertainty (Beckman and Barry, 2007; Verganti, 2009).

At the same time, digitization is rapidly gaining momentum in all areas of the modern workplace, and virtual work settings and collaborative activities in virtual spaces have become established in many domains (e.g., Annosi et al., 2023; Gallego et al., 2021; Gilson et al., 2015; Gratton, 2021; Gupta et al., 2022; O'Leary et al., 2014). These changes have not only affected innovation management in general (Appio et al., 2021; Brucks and Levav, 2022; Verganti et al., 2020; Wetzels, 2021; Wilson et al., 2023), but also DT in particular (Redlich et al., 2018). Highly interactive on-site DT workshops are increasingly supported by all kinds of software tools (e.g., Miro, Mural) or shifted to a virtual format altogether (e.g., Zoom, Microsoft Teams) (Schoormann et al., 2020). As a result, workshop participants often no longer meet in person to interact, brainstorm, and prototype together, but perform these activities in virtual environments.

While a virtual environment allows firms to implement DT workshops with greater efficiency and at a greater scale, virtual formats may potentially undermine one of the central tenets of the DT method: its experience-based character (Brown, 2008; Brown and Martin, 2015; Oliveira et al., 2024). First, effective DT processes rely on intensive and repeated interactions among end users, design thinkers, and other stakeholders. However, these interactions change fundamentally in virtual environments as the participants are spatially separated and no

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longer interact in person. In this regard, past research on virtual work environments suggests that distributed work may affect how individuals relate to their work environment and their co-workers (e.g., Klitmøller and Lauring, 2016; Leonardi et al., 2024). Second, research has also emphasized the importance of immersive, embodied experiences in the DT process, such as engaging with objects and materials (Lindgaard and Wesselius, 2017; Rylander Eklund et al., 2022). Such experiences, however, are potentially hampered in disembodied and virtual settings.

As these arguments suggest, moving from predominantly physical, on-site formats to virtual formats constitutes more than a change in the medium; instead, this change may have far-reaching consequences for how DT participants experience the DT process. Existing research provides initial support for this notion, showing that participants' cognitive experiences shape the effectiveness of DT projects: On the one hand, cognitive obstacles can interfere with and thwart the DT process (Butler and Roberto, 2018; Nagaraj et al., 2020); on the other hand, DT itself can help decision-makers in reducing their cognitive biases (Liedtka, 2015, 2018, 2020).

To summarize, while recent years have witnessed an increasing tendency to transfer DT projects to virtual settings, there is little research that helps explain how this shift affects the process as well as the outcome of these projects. In this research, we address this gap by pursuing two interrelated research questions (RQ):

RQ1: *What are the cognitive mechanisms occurring at the individual participant level when utilizing a virtual DT format compared to a physical format?*

RQ2: *How do virtual DT formats influence both the process and outcomes of DT projects?*

To address these questions, we draw on construal level theory (CLT) and embodied cognition (EC). These theories offer a comprehensive frame of reference for understanding how participants' experiences and cognitions may vary across physical and virtual DT formats, as they account for both the influence of distance-related factors and the embodied nature of mental processes. Whereas CLT describes how people form mental representations of events they cannot experience directly (Trope and Liberman, 2010), EC sheds light on how people's cognitive experiences are informed by their bodily experiences (Barsalou, 2008). Drawing on this theoretical background, we derived tentative propositions regarding the potential influence of virtual DT formats on participants' experiences and the overall outcomes of these projects. These propositions served as starting points for our subsequent empirical study, in which we employed an exploratory qualitative approach. We conducted 41 in-depth interviews with DT experts from research (e.g., Hasso-Plattner-Institute, Macquarie University, TU Delft) and practice (e.g., Ford, Henkel, SAP, Deutsche Telekom) to explore the distinct cognitive mechanisms underlying physical and virtual DT formats.

Our results make important contributions to research and practice. From an academic perspective, by showing how the specific format of DT projects affects participants' cognitive experiences, we contribute to research on the individual-level mechanisms and effects underlying the DT process (e.g., Auernhammer and Roth, 2021; Liedtka, 2015; Lynch et al., 2021; Thompson and Schonthal, 2020) as well as the outcomes of the DT process (e.g., Beverland et al., 2015; Nagaraj et al., 2020; Seidel and Fixson, 2013; Zheng, 2018). We show that a change from a physical to a virtual format has far-reaching implications for how design thinkers make sense of users' experiences, how they form a mental representation of user needs, and how they translate this representation into a tangible solution. In this sense, our findings not only relate DT to current managerial and technological developments (Eling and Herstatt, 2017), but also answer recent calls to embed DT into a larger theoretical discourse (Dell'Era et al., 2020; Verganti et al., 2021). On a more fundamental level, our findings contribute to a better understanding of how to organize innovation activities in the digital age (e.g., Dabić et al., 2023; Rindfleisch et al., 2020; Sapsed and Tschang, 2014; Wetzels, 2021; Xie et al., 2024).

From a managerial perspective, our research has important implications for the effective implementation of DT processes. Our findings suggest that physical formats are not necessarily superior to virtual formats in terms of generating effective outcomes; instead, both formats have distinct advantages that can be mapped onto the specific challenges arising in the different phases of the DT process. Whereas process steps that require convergent thinking (e.g., defining a latent need based on the observation of users) may potentially benefit more from virtual formats, physical formats are generally considered more suitable to those steps that involve divergent thinking (e.g., identifying the solution space to address a latent need). Against this background, an ideal DT process may be hybrid and combine physical and digital elements systematically. However, it is important to acknowledge that the effectiveness of each format can be context-dependent, considering the specific requirements of different tasks and iterations within each process step.

2. Theoretical background

In this section, we discuss three research streams that are pertinent to our research questions. First, we provide a review of the DT literature, with a focus on the principles and process of the DT approach. Next, we discuss two psychological theories that provide a broad frame of reference for understanding how a change from a physical to a virtual setting may affect DT participants' experiences and outcomes of the DT process. Whereas the first of these theories—construal level theory—examines how people form mental representations of situations and events that are psychologically distant and thus cannot be experienced directly, the second theory—embodied cognition—discusses how people's cognitions are affected and shaped by their bodily experiences.

2.1. Design thinking

Even though DT has attracted great attention in the academic as well as practitioner literature (e.g., Brown and Martin, 2015; Liedtka, 2015; Noble, 2011; Seidel and Fixson, 2013), a generally accepted definition of DT has not yet emerged and even the term itself has been the subject of debate (Auernhammer and Roth, 2021; Elsbach and Stigliani, 2018; Luchs and Scott Swan, 2011; Verganti et al., 2021). However, most scholars conceptualize DT as an iterative, human-centered approach to innovation that draws on and is inspired by approaches that are typical of the design profession (Brown and Katz, 2011; Carlgren et al., 2016; Dell'Era et al., 2020; Magistretti et al., 2021; Seidel and Fixson, 2013).

A great number of studies have shown that DT practices can increase firms' innovation performance (Candi and Saemundsson, 2011; Dell'Era and Verganti, 2007; Kamble et al., 2023; Luchs et al., 2016; Robbins and Fu, 2022). To better understand these effects, scholars have examined DT from different perspectives, focusing on the specific methods within DT processes (Liedtka, 2018; Seidel and Fixson, 2013) or the mindset engendered by DT practices (Dong et al., 2016; Dunne and Martin, 2006; Schweitzer et al., 2016). In this research, it is the process-based view that is of particular importance. This view argues that DT processes consist of distinct phases that DT teams go through in a sequential, yet iterative manner. One particularly popular framework is the one from Stanford's d.school (2023) that identifies five phases: empathize, define, ideate, prototype, and test (Carlgren et al., 2016; Liedtka, 2015; Micheli et al., 2019).

In the *empathize* phase, the DT team aims to develop a deep understanding of users' latent needs. Such understanding often entails the use of qualitative, ethnographic research methods that allow design thinkers to observe users in their natural environments and to fully immerse themselves in their experiences and perspectives. Hence, this phase emphasizes the importance of embracing an open, curious, and empathetic mindset (Brown, 2008).

Next, the *define* phase focuses on data synthesis to gain a refined understanding of the problem and frame the design challenge. Here, design thinkers aim to find patterns by synthesizing research findings

and considering the problem and solution space in a holistic, unconstrained, and open-ended manner (Kolko, 2015; Lockwood, 2009).

In the third phase, *ideate*, a wide variety of innovative ideas and solutions are explored. Different techniques, such as brainstorming, storyboarding, and brainwriting are often used to enable creative thinking. Visualizing ideas is considered particularly important in this phase to enable design thinkers to move from *thinking* to *doing* and to overcome the ambiguity of abstract, verbal explanations (Drews, 2009; Flaherty, 2005; Micheli et al., 2019).

Next, in the *prototype* phase, ideas are put into action and translated into tangible and experienceable representations of the ideas.

Lastly, in the *test* phase, the prototypes are tested with potential users to generate feedback. This may lead to a redefinition or re-examination of the original point of view. Thus, this phase relies heavily on experimentation to enable rapid and frequent cycles of learning (Lockwood, 2009).

In addition to conceptualizing DT as a process, existing research has also characterized DT as a set of behavioral practices that serve specific purposes and leverage innovation within a larger process (Carlgren et al., 2016; Dell'Era et al., 2020; Micheli et al., 2019). Commonly discussed practices include a user focus, problem framing, visualization, experimentation, and embracing diversity (Carlgren et al., 2016; Liedtka, 2015). It is important to note that these two views complement each other rather than being at odds. That is, while DT combines intuitive with analytical thinking and convergent with divergent thinking (Dunne and Martin, 2006), the importance of these mindsets may differ across the different phases of the DT process. For example, defining a latent need may be best served by an analytical and convergent mindset. In contrast, an intuitive and divergent mindset may be particularly effective for thinking of a broad solution space and identifying previously unthought-of ideas.

A common element of many of these practices is that they require a certain level of physical, embodied interaction (e.g., immersing oneself in the user's natural habitat, working jointly on an initial prototype, and refining prototypes through repeated iterations) (Magistretti et al., 2021; Plattner et al., 2011; Stigliani and Ravasi, 2012), which is at odds with the notion of disembodied and distant virtual environments. The existing literature on DT does not address how a shift to virtual environments and the resulting absence of physical experience might influence the participants in DT projects and the respective outcomes. However, two prominent psychological theories—construal level theory and embodied cognition—can offer an initial analytical framework for addressing this issue, as they focus on the two major changes entailed by virtual DT formats: the lack of direct interaction as well as direct bodily experiences.

2.2. Conceptualizing design thinking through the lens of construal level theory

Construal level theory (CLT) asserts that a stimulus (i.e., an event, a decision, a person, or an object) that is not part of a person's direct experience must be mentally construed (i.e., imagined) and thus feels "distant" in a psychological sense (Trope and Liberman, 2010). Based on this notion, research on CLT has focused on two main questions: First, the specific determinants of psychological distance, and second, the consequences of psychological distance for perception, communication, and evaluation.

Regarding the determinants of distance, research has shown that the psychological distance experienced in response to a stimulus is determined by the objective distance to that stimulus (Trope and Liberman, 2010). In particular, psychological distance is shaped by four types of objective distance, namely temporal, spatial, social, and hypothetical distance (Trope and Liberman, 2010). For example, an event (e.g., a concert) will feel psychologically closer when it takes place in a near location (e.g., one's hometown) compared to a distant location (e.g., another country). In addition, people who are central to one's self (e.g., a spouse) will be associated with lower psychological distance than people who are less central (e.g., a colleague). Consistent with this notion, research has found that employees engaged in virtual or remote work environments experience higher psychological distance because such settings lack direct, in-person interaction (e.g., Klitmøller and Lauring, 2016; Leonardi et al., 2024). Building on these findings, one may argue that participants in virtual DT sessions (e.g., design thinkers, end users, or other stakeholders) also experience higher psychological distance because they are spatially and socially removed from the other participants involved in the process.

Regarding the consequences of distance, research has shown that psychological distance has a profound effect on perception and evaluation (e.g., Rim et al., 2009), interpersonal communication (e.g., Stephan et al., 2010), and decision-making (e.g., Trope et al., 2007). In essence, how a stimulus is mentally construed affects how that stimulus is used in subsequent cognitive operations. When psychological distance is high, individuals tend to construct a more abstract and high-level representation of a stimulus, emphasizing its broad significance rather than specific details (Trope and Liberman, 2010). Consequently, higher psychological distance fosters an orientation on outcomes as well as holistic thinking during decision-making processes (Nguyen et al., 2019; Schirner et al., 2023; Ülkümen and Cheema, 2011). When, however, psychological distance is low, individuals tend to form a concrete, low-level representation of the stimulus that involves detailed and context-dependent information (Trope and Liberman, 2000, 2010). Put differently, high distance levels will lead people to see the "forest" rather than the "trees", whereas the reverse is true for low distance levels (Smith and Trope, 2006).

Again, these findings may further enhance our understanding of the effects of shifting DT processes from physical to virtual settings. As such, the setting of the DT process may not only influence the understanding of the problems to be solved but may also affect the solutions that are envisioned to help solve these problems. Put differently, a key feature of the DT process (i.e., the extent to which the process takes place in physical or virtual environments) may determine how the participants mentally construe the key object of reference (i.e., the problem to be solved in the DT process and the solution(s) envisioned for this problem).

For instance, interacting with users through a digital screen may prevent design thinkers from fully immersing themselves in the users' environment and may lead them to form a more abstract and schematic understanding of their needs (Marwede and Herstatt, 2019). Furthermore, shifting to a virtual format may also affect the ideation stage (Rylander Eklund et al., 2022; Verganti et al., 2021). The higher psychological distance experienced in virtual settings may affect the process of idea generation and may result in broader, more abstract prototypes and solutions (Förster et al., 2004; Jia et al., 2009). In a similar vein, design thinkers who conceptualize a user problem at a higher psychological distance may also be prone to over-optimism and underestimate practical issues (Steinbach et al., 2019). As these arguments indicate, DT sessions held in physical versus virtual environments may trigger varying degrees of psychological distance, which, in turn, may affect the process as well as the outcome of these sessions.

2.3. Conceptualizing design thinking through the lens of embodied cognition

Research on embodied cognition (EC) posits that cognitive processes emerge from social and physical interactions of the body with the environment (Glenberg et al., 2003) and suggests a bidirectional relation between sensorimotor and cognitive processes (Barsalou, 2008; Foglia and Wilson, 2013; Markman and Brendl, 2005). That is, the way we think and feel is strongly influenced by the perceptual and sensorimotor systems, including our bodily movements and physical interactions with the world (Glenberg, 2010).

Of relevance to the DT context, EC has been applied to problem-

solving, learning, emotion, and language (Glenberg et al., 2004; Shapiro, 2011). Specifically, studies have shown that bodily movements and sensorimotor experiences can activate internal cognitive processes, which, in turn, facilitate subsequent cognitive performance. For example, studies in the field of learning have found that handwriting, compared to keyboard writing, leads to better memory and visual recognition. Writing letters, words, and sentences by hand provides continuous visual and motor feedback to the brain, whereas locating and tapping keys does not generate the same level of sensory feedback (Mangen and Balsvik, 2016). Furthermore, individuals often use spontaneous gestures to aid them in solving difficult problems (Chu and Kita, 2011; Cook et al., 2008). Gestures and hand movements can improve performance by giving learners an alternative, more holistic way of representing new ideas. In line with this notion, children solving math problems often use their hands; however, performing these hand movements deliberately also enhances math performance (Goldin-Meadow et al., 2009). Likewise, learning can also be enhanced through interacting with tangible objects. For instance, students learning about the anatomy of the heart exhibited increased performance when they were able to engage with a plastic model of the human heart rather than just a digital representation (Skulmowski et al., 2016).

Research on EC is also relevant for understanding the process and outcomes of DT. As such, existing research on DT has emphasized the crucial role of aesthetic experimentation and sensory engagement (Rylander Eklund et al., 2022). Core practices from the design discipline such as the ability to use one's hands for gesturing, experimenting with artifacts and materials, and building and refining prototypes play a crucial role in ensuring the success of DT processes (Brown, 2008). These practices not only enable DT participants to communicate their ideas more effectively but also facilitate the emergence of these ideas in the first place (Rylander Eklund et al., 2022). In line with these findings, more specific research has started to integrate EC into theorizing on DT, emphasizing that DT constitutes a holistic, whole-body experience that requires experiences and interactions with the physical world (Diethelm, 2019; Kimbell, 2012; Lindgaard and Wesselius, 2017). For instance, Slepian and Ambady (2012) found that participants showed greater creativity in a problem-solving task when they had traced fluid (vs. non-fluid) drawings before this task. Seemingly, the experience of fluid movement facilitated fluid thinking, enabling participants to generate more creative ideas.

However, such sensorimotor experiences appear incompatible with the concept of a remote and disembodied virtual DT process. That is, in virtual environments, DT participants lack the opportunity for embodied, sensorimotor experiences, which may impact cognitive processes as well as the outcomes of the DT process. In this regard, Verganti (2017) succinctly notes that the removal of felt-sense and aesthetics from DT processes is akin to a "lobotomy" that risks extinguishing DT's creative power.

Summarizing, based on the theories reviewed above, we propose that changing the DT format from physical to virtual entails more than just a change of format. Rather, this change may have far-reaching consequences for how participants discover opportunities for innovation as well as how they generate ideas intended to exploit these opportunities. In the following study, we explore these propositions in greater detail by analyzing the individual phases of the DT process against the background of CLT and EC and discussing how the transition from a physical to a virtual environment impacts these phases.

3. Methodology

3.1. Research setting and sampling

To comprehensively explore how the implementation format affects the experiences of participants in DT processes and the outcome of these processes, we chose an exploratory qualitative approach (Eisenhardt, 1989). We carefully recruited a total of 41 experts for in-depth interviews, selected from three different backgrounds: experts from a) different industry areas (e.g., Ford Motor Company) who lead DT projects in their organizations; b) academia (e.g., Hasso-Plattner-Institute) who teach and research about DT; and c) consultancies (e.g., Deloitte) who implement workshops and entire projects in other organizations. Thus, our sampling strategy focused on recruiting domain experts with extensive experience in various areas of DT, aiming to capture diverse perspectives on DT within virtual environments. Experts were recruited through a variety of channels. First, we drew on our existing networks of DT experts in the three fields, who then referred us to other potential interview partners. In addition, we used the online network LinkedIn to acquire further informants. All informants had at least three years of experience in DT and had accompanied several DT projects in both physical and virtual formats. Table 1 lists the final sample of expert informants along with descriptive information.

3.2. Data collection

A total of 41 interviews with DT experts were conducted via Zoom between March 2021 and December 2022. We used a semi-structured interview guide that was organized as follows. First, we asked informants about their experience in DT projects and their understanding of DT in general. Next, the interviews concentrated on how informants perceived the change of DT projects to virtual formats. Following this, we focused on the different phases of the DT process. Informants were led through the five-step DT process from Stanford's d.school and were asked to evaluate the impact of running DT in a virtual format on both the implementation and the outcomes of each phase, in comparison to a physical format. This semi-structured approach allowed us and the informants to freely raise new issues and to test them iteratively in the interviews (see Appendix A for the interview guide). Recordings of the interviews totaled 42 h, with an average of 62 min per interview. The audio recordings were transcribed, resulting in a total of over 900 single-spaced pages. Interviews with experts were conducted until theoretical saturation was reached, that is, when additional interviews did no longer reveal new insights.

3.3. Data analysis

To structure the data analysis, we relied on an iterative procedure of sequential coding (Eisenhardt, 1989). Specifically, we followed three main steps, moving from data-based first-order concepts to a more abstract analysis where we linked the findings of the interviews to our theoretical foundation (Gioia et al., 2013). The first round of data analysis involved reading the data material several times and working with pen and paper to capture initial ideas, memos, and codes. In the following rounds, we used the MAXQDA software to allow for a software-assisted cross-interview analysis. The data were first coded by the first author and the most relevant quotes were extracted to establish a codebook. To enhance the quality of the coding and ensure a thorough and reliable analysis, codes were discussed, revised, and sorted by the research team in several rounds.

The first-order concepts were developed based on in-vivo coded data. In this step, the coding purely picked up the terminology of the informants (Gioia et al., 2013). Based on similar conceptual patterns, these codes were then combined and regrouped into second-order themes. In contrast to the previous step, these codes were inspired and guided by the literature on EC and CLT to enhance the interpretation of our initial findings. By going back and forth between the data and the literature, we identified additional quotes for first-order concepts that further informed second-order themes. These themes, in turn, were consequently reinterpreted and regrouped. Finally, the second-order themes were aggregated and assigned to the five stages of the DT process and core implications for each phase were developed, inspired by the DT behavioral practices (Carlgren et al., 2016; Micheli et al., 2019).

Table 1
List of expert informants.

No.	Background	Specification	Role	DT experience (in years)	Interview length (in min)
1	Industry	Automotive	Project/innovation manager	5	56
2	Industry	Automotive	Innovation manager	6	60
3	Industry	Automotive	Project/innovation manager	7	77
4	Industry	Automotive	Innovation manager	5	78
5	Consultancy	NPD	Design consultant	16	68
6	Consultancy	NPD	Design consultant	8	83
7	Academia	Industrial design	Assistant professor	12	72
8	Academia	Innovation	Innovation strategist	6	78
9	Consultancy	Innovation	Innovation strategist	4	82
10	Academia	Marketing	Professor/design thinking coach	6	68
11	Industry	Software	Innovation manager	23	52
12	Academia	Entrepreneurship	Professor	15	67
13	Industry	Software	Design lead	6	71
14	Academia	Entrepreneurship	Ph.D. design thinking/coach	5	61
15	Academia	Social innovation	Ph.D. design thinking/coach	8	59
16	Consultancy	Innovation	Managing partner/coach	9	53
17	Academia	Digital innovation	Professor	7	54
18	Industry	Innovation	Design thinking expert/coach	11	41
19	Industry	Software	Junior UX designer	3	55
20	Industry	Fashion	Director of design	12	44
21	Industry	Software	Product designer	4	62
22	Industry	Insurance	Innovation facilitator	4	52
23	Industry	Online market	Product design manager	11	51
24	Consultancy	Innovation	Innovation consultant/coach	12	77
25	Industry	Pharma	Service design experience lead	20	65
26	Consultancy	Innovation	Technology innovation manager	4	59
27	Industry	Architecture	Service designer	10	41
28	Academia	User experience	Design thinking facilitator	10	40
29	Industry	Consumer products	Ideation expert/idea manager	3	58
30	Industry	Consumer products	Ideation/design thinking expert	5	50
31	Consultancy	Innovation	Innovation consultant	6	42
32	Industry	Innovation	Design thinking trainer	6	73
33	Academia	Design thinking	Professor/director	15	40
34	Industry	Telecommunication	Expert operational excellence	6	70
35	Industry	Telecommunication	Creative director	16	84
36	Industry	Telecommunication	Chapter lead	6	75
37	Industry	Telecommunication	Design thinking coach	3	71
38	Industry	Software	Service design lead	5	49
39	Industry	Software	Senior business model manager	8	67
40	Consultancy	Management	Market offering innovation lead	21	58
41	Industry	Automotive	Leader innovation management	9	53

4. Findings

In the following, we will discuss our findings for each phase of the five-stage DT process, focusing on how the change from physical to virtual format affects participants' cognitive experiences and the overall outcomes of these projects compared to traditional physical formats. Table 2 documents our data structure and provides additional evidence for our conceptual themes from the perspectives of the experts.

4.1. Empathize

The empathize phase focuses on building a rich and comprehensive understanding of users' values, challenges, and problems (Brown, 2008). Our interviews indicate that a virtual setting may restrict this process at two different levels. First, virtual settings may constrain learning processes as only parts of the sensorimotor system are used. Second, as a result, the depth and breadth of the insights gained during this process may be affected. Both of these themes are further discussed below.

4.1.1. Emotional immersion into the environment

Research on EC argues that people absorb information from the environment to obtain a more holistic understanding of a stimulus (e.g., a person, an event, or an experience) (Wilson, 2002). That is, although visual perception is an important source of information, bodily movements as well as the feedback from the environment to these movements are integrated into visual processing (Foglia and Wilson, 2013). Put differently, individuals' understanding of a specific situation is also determined by what they *do* in this situation.

In line with this notion, our informants reported that understanding is not only achieved through listening to users' verbal statements, but also through immersing themselves in the users' environment. Essentially, empathy requires living through the same experience and enacting the same behaviors as users, for which reason design thinkers often strive to be present in the users' physical surroundings. This may also allow design thinkers to recognize patterns that users may be unaware of (Brown, 2008). However, as bodily immersion into the user's environment is not possible in virtual settings, design thinkers need to rely more strongly on verbal reports than they normally would. Hence, interacting with users only through digital means may also affect the understanding of the user's emotional experience. According to EC, the perception of an emotional stimulus and the retrieval of an emotional memory are not purely based on cognitive processes, but encompass all sensory modalities (Niedenthal, 2007). In other words, seeing, hearing, smelling, and feeling are all involved in the construction of an emotional experience. In line with this view, one expert noted that fewer insights on users' emotional states may be generated when the empathize phase is conducted virtually:

Table 2
Data structure and additional evidence.

Second-order themes	First-order concepts	Selected expert quotes
Aggregate dimension: Empathize		
Emotional immersion into the environment	Sensory perception of the atmosphere	Now, there is a real difference if I'm working with the company, normally, you go through the company and you grasp the atmosphere in the building, how they talk to each other, you've got a clue on the company culture. (E8)
	Bodily expressions and non-verbal signals	The social interactions are different once you're in a room together, or in a location together and you can see each other, see each other's body language, […]. That makes a huge difference both when trying to understand stakeholders, but also when working as a group on analyzing research. (E5)
	Freedom of exploration	It is so much harder to get a grasp on the actual usage situation in a digital setting. You depend so much on what the user will tell or show you compared to a setting where you can see things for yourself and then start asking questions. (E2)
Depth and breadth of user insights	Informational content and user insights	Certain information you cannot get to, it doesn't become apparent [...]. I think it [virtual approach] is a useful addition to analog design thinking, if you want to call it that, to integrate data, sources, digital flows. […] But there is no way you can substitute it the other way around. (E12)
	Communication style	You lose that connection with people, and through that connection there is some non-verbal communication in the observation process. You don't have that [virtually]. You lose that, and by communicating with someone through a screen, you lose 40 % of that person's reality. (E39)
Aggregate dimension: Define		
Efficiency, goal orientation, and big picture	Efficiency in data analysis	It was even more effective because we created our online tool, like Miro, where we put all information together. (E18)
	Transparency and visualization of the collected data	I think that it [Miro] is great, that the documentation has become better and easier because you have a room that is open 24 h a day, 7 days a week, where you can compile all the information. […] Afterwards, you have a huge board where you can always track everything that has happened. (E16)
Aggregate dimension: Ideate		
Environment as a source of creativity	Physical movements and sensory factors	We could body-storm, which is very different than brainstorming because you're actually moving your bodies, which makes the connection. (E27)
	Spark of collaboration, energy, playfulness	In offline formats, we always used certain tricks – and that is what I meant by the event character of innovation, which is often laughed at, but definitely has a lasting impact on the participants. They somehow open up and think differently. (E9)
	Serendipitous conversations	These random conversations, they occur much less frequently [online]. And I think you need those to come to an understanding. And for that, you can meet online […], but that's where the efficiency of online meetings maybe has a sabotaging effect. Maybe you can put it that way: A little inefficiency doesn't hurt in developing [ideas]. (E4)
	Picking up and responding to signals	Collaboration with your team members and colleagues, the nuances, the picking up on signals. How they're feeling, how they're doing, having these inside conversations […]: missing online. (E10)
	Psychological safety and trust	Also, in my last project, there was little trust in many instances and that naturally inhibits creative work and progress [...]. (E35)
Outcome of idea generation	Quantity of ideas	The further development [of ideas] then happened [on-site] in interactions. You stood in front of walls where clusters were collected […], and you continued spinning out the ideas very quickly. You can simulate that [virtually], but I would cautiously say that the output is measurably less. (E9)
	Level of abstraction of ideas	In online workshops, I see more futuristic, more abstract, more of digital ideas because we are already on a digital platform, so that actually indirectly or in our subconscious mind, we are already in this online virtual world. (E26)
Aggregate dimension: Prototype		
Touching and thinking with hands	Interacting with prototypes	At the early stage of prototyping, it's also you want them to stop thinking here and basically think with their hands and further develop an idea. Online, I feel it's again, much more focused on 'I'm thinking it through. I'm in front of the screen.' (E10)
	Power of imagination	The touch experience of products […] it always impacts the imagination. You're lacking data, because you don't have access to the prototype [virtually]. (E20)
	Product, project and iteration dependency	Well, it depends on the stage of the project. With increasing iterations, the concept becomes more concrete and you start focusing on implementation. At one point, this is pure digital design work. The next step would then be a very simple physical prototype. It's normal to go through this digital phase and build digital prototypes in the early stages. (E1)
Aggregate dimension: Test		
Interaction possibilities and feedback	Information processing	We can express and share our feelings toward the prototype much faster and this information can flow immediately into further development. The experience of the prototype is real and because of that the evaluation of the prototype is better, the quality of the evaluation is better. (E4)
	Context as a source of information	It's all a very shallow form of real-life because you can't fully see someone using the prototype in context and see how it is misused or differently interpreted all that is unreasonable. Because you will just functionally put someone through a process online. You miss all the things where it goes wrong or just product testing. (E7)
	Experimentation to see the user's reaction	The feedback is not that personalized. I like to be on spot to see how the reaction is, what the body language is telling me. (E22)
Analytical and goal-driven testing procedure	Analytical evaluation criteria of prototypes	In my view, it's because these are relatively analytic, pragmatic activities that are not associated with that much uncertainty. […] Coming up with the questions for the question guide and the testing guide can, I think, be done in a structured way in a moderated setting, in a video call. (E17)
	Social pressure and trap of selling prototypes	I found that [virtual testing] cool because you're literally giving away the prototype, letting people test it, you're not there to ask them constantly, 'Do you like it? Don't you like it?'. That, I thought was a cool thing that maybe you can't do even in physical workshops, you usually are in front of people and you're hearing from them right away. (E15)

> "The first step in empathizing, we are not in each other's context, only partially. That's a very big difference. […] it's really difficult to fully see the other one's perspectives. Empathy means that you should be able to immerse in someone else's situation. How can you immerse fully if there is just a digital screen in front of you and you can't sense, smell, or see the full person? You lack communication about emotions."
>
> (Expert 7)

4.1.2. Depth and breadth of user insights

Apart from restricting the immersion process, virtual settings may affect how design thinkers communicate with users and how they draw insights from these exchanges. People often focus on nonverbal signals to analyze and contextualize the verbal statements of others (Bonaccio et al., 2016; Buck and VanLear, 2002). However, in virtual settings, the possibility to perceive non-verbal signals is restricted and individuals will need to rely more strongly on verbal communication, which, in turn, reduces the transfer of knowledge (Wilson et al., 2013). As a result, more implicit insights may get lost, as exemplified by the following expert statement:

> "When conducting the empathize phase in-person, having empathy interviews, […] we will pay attention to body language, right? Like a person smiles, looks down, looks up or just any kind of body language the person will make […]. With virtual, although I have another person in front of me, it is hard to see the body language."
>
> (Expert 25)

Moreover, a virtual setting may not only affect *what* users and design thinkers talk about, but also *how* they talk about it. In this regard, research on CLT shows that psychological distance affects the nature of verbal communication. For instance, Fujita et al. (2006) found that people who were asked to describe spatially distant events (as opposed to near events) used more abstract language. In the current context, as end users and design thinkers are spatially distant in virtual settings, they may inadvertently resort to more abstract language to talk about their understanding of the problem to be solved. Again, this argument is reflected in an expert statement:

> "The quality of the questioning, of course, will be different again. […] When I discuss with the user on-site, we look each other in the face, he can show me something directly, and I understand the things that he says. This all gets lost in a digital interview. His experiences will be the same, he will pay attention to the same things, but he will communicate them differently."
>
> (Expert 1)

Finally, these changes in interpersonal communication may affect the kinds of insights that design thinkers generate. As exchanges in virtual environments are associated with higher psychological distance (Wilson et al., 2013), design thinkers may generate more abstract insights from their interactions with end users and may miss more concrete details about the (underserved) needs they are trying to address (Trope et al., 2007; Trope and Liberman, 2000, 2010). However, to identify true opportunities for innovation in the empathize phase, design thinkers are typically reliant on rich and contextualized information, as expressed by one expert:

> "If the teams are working remotely in different geographic locations, then being limited to maybe doing a Zoom call […], but not observing them [users] in public spaces, et cetera. With that [empathizing virtually], we might never get to new observations, and that will prevent us from [gaining] insights that we haven't had before. That's a risk."
>
> (Expert 10)

While virtual environments may impact the type of insights that can be captured, they also offer the opportunity to broaden the spectrum of perspectives. This may positively contribute to a more comprehensive and diverse understanding of problems, facilitated by the mitigation of geographical distances and temporal constraints. The global reach afforded by virtual platforms enables engagement with a greater number and a more heterogeneous array of potential users on a global scale. Importantly, this expanded reach aligns with ecological benefits and is characterized by enhanced time and cost efficiency.

4.1.3. Summary and synthesis of the empathize phase

Our interviews suggest that executing the empathize phase in a virtual setting has profound implications. As such, being part of the user's physical environment allows design thinkers to have a fuller sensory experience and to explore the problem space more comprehensively. Virtual environments are more restricted in this regard and may lead to a more limited understanding of the problem space. Moreover, as interpersonal exchanges are more psychologically distant in virtual settings, design thinkers may also form more abstract mental representations of the challenges and needs expressed by end users (Wiesenfeld et al., 2017).

4.2. Define

The define phase comprises the synthesis of the insights gathered, followed by the definition of the problem space. Overall, informants considered virtual settings very positively in this phase. On a process level, the usage of digital whiteboard tools enabled a more goal-oriented workflow, thus increasing efficiency. Further, the possibility to directly digitize and visualize all information facilitated seeing the "big picture". These findings are further explored below.

4.2.1. Efficiency, goal orientation, and big picture

In the define phase, DT teams need to synthesize the idiosyncratic viewpoints expressed by end users to achieve a common understanding of the problem at hand. Arguably, such an understanding is facilitated by higher psychological distance. As such, higher distance typically encourages a more abstract and decontextualized form of processing, which not only encourages a stronger orientation toward long-term goals, but may also help in recognizing the "big picture" more readily (Wakslak et al., 2006). Conversely, lower distance triggers more concrete, contextualized processing where incidental details may overshadow more abstract, overarching themes (Trope and Liberman, 2000). These arguments align with our interviews: Informants remarked that the digital tools they had at their disposal allowed them to analyze the data they had gathered in the previous phase in a more structured and systematic manner, encouraging a greater goal orientation in the define phase. As one expert noted:

> "In this respect, to be honest, the collaboration [in the virtual define phase] is perhaps even more effective or efficient, because with good project management you actually distribute the work packages, meet, compile things, discuss, and everyone does their thing and derives conclusions from it."
>
> (Expert 9)

In addition, viewing all the information gathered from a more distant perspective allowed for a holistic perception of the problem space. Informants noted that recording the entire user journey and visualizing it with the help of virtual boards such as Miro or Mural focused their attention on a comprehensive, holistic picture. In this manner, conducting the define phase in virtual settings may allow for an unconstrained synthesis of all findings and rapid learning cycles, thereby enabling DT teams to identify patterns in the data more effectively. Interestingly, these findings may imply that virtual innovation environments are suitable for those tasks that require convergent thinking, that is, tasks that require a logical rather than creative approach to finding clearly defined outcomes. These advantages were pointedly summarized by an expert:

"As a coach and I think as participants, what people love, is that […] the whole journey is right in front of you. In physical workshops, I always tried to keep one big paper, […] but, amazingly, the whole learning experience is there [virtual], all the post-its, everything they [the participants] have shared and thought about, day one to the last […]. Yes, it's just really good for learning that you can go back and reflect."

(Expert 15)

4.2.2. Summary and synthesis of the define phase

To summarize, our findings suggest that virtual innovation environments may help increase the effectiveness of the define phase. As such, one of the aims of this phase is to consider the problem and solution space in a holistic, unconstrained, and open-ended manner (Carlgren et al., 2016). Our findings suggest that this mindset is facilitated in virtual settings as such settings are likely to trigger a higher level of psychological distance and may stimulate a more structured and goal-oriented analysis of user needs and potentially effective solutions (Trope and Liberman, 2000). This, in turn, may help DT participants in seeing the "big picture" more readily.

4.3. Ideate

The ideate phase aims at generating a great variety of innovative ideas. To accomplish this goal, DT offers a wide range of playful tools that enable creative and open thinking. The use of such tools, however, is significantly restricted in virtual ideation workshops. This effect occurs across two dimensions: First, at an input level, virtual sessions lack spatiality, social interaction, and the possibility for being playful within the environment. Second, at an output level, social and spatial distance change the outcome of virtual sessions in terms of the ideas generated. Below, we will shed light on these shifts in more detail.

4.3.1. Environment as a source of creativity

From the perspective of EC, cognition is not purely seen as an activity of the mind but is instead shaped by the totality of the sensory input available in a given situation (Wilson, 2002). In addition, studies have shown that certain types of physical movements can stimulate creativity as they activate internal cognitive processing (Slepian and Ambady, 2012). In line with these findings, interviewees often remarked that the ideation environment, both in a structural and social sense, is a crucial source of inspiration. This was considered to be especially critical in ideation sessions that typically require divergent thinking. However, compared to on-site workshops with physical materials, in virtual sessions, motoric actions and sensory experiences are much more limited. For example, interviewees described that walking along the wall of ideas and moving around the room can have positive effects on one's thinking. In contrast, virtual ideation sessions did not allow for such possibilities, as noted by one expert:

"Being able to step out of the room, get a different perspective. Leaving the room, looking at post-its from a distance, all these things are limited."

(Expert 10)

In addition, studies from the field of learning and education have shown that handwriting in comparison to writing on a keyboard enhances cognitive performance. The continuous visual and motoric feedback provided from writing (e.g., movement in making lines, dots, and curves) constantly provides the brain with information (Mangen and Balsvik, 2016). In the current context, experts referred to the beneficial effects of writing down ideas per hand in ideation workshops. Informants preferred working with physical materials such as pens and post-its in this phase, as this stimulated their creativity. However, in virtual ideations, this physical process was substituted by typing ideas on virtual post-its:

"You can do less with your hands, just typing, which again is the same thing you normally do with other types of work. You're much less creative."

(Expert 2)

Our findings also highlight the impact of the social environment. EC argues that the emotional connection to other people is influenced and shaped by the environment (Williams and Bargh, 2008). In this manner, groups may affect and extend the cognitive powers of the individual (Semin and Smith, 2002). Supporting this view, interviewees often mentioned that physical meetings allow for the formation of an emotional bond and trust between participants, which, in turn positively affects the creativity of individual members in ideation sessions. In this context, one expert mentioned:

"I feel, again, that it is much harder for the teams to build that trust, to build up that psychological safety, even if you do the same activities online."

(Expert 10)

Moreover, open discussions, curiosity, and playfulness are central components during ideation sessions as they may help to establish rapport between participants and may increase the commitment to the DT task (Carlgren et al., 2016). However, such effects may be contingent on the physical environment. Figuratively speaking: For participants to think outside of the box, they may actually need to leave their own box. That is, extraordinary ideas are more likely to emerge in extraordinary environments, (e.g., a carefully crafted DT room) than in ordinary environments (e.g., one's office or home). Hence, the physical environment and the bodily interaction within the environment may act as a source of inspiration.

However, such effects are dampened in virtual ideation sessions, not least because such sessions discourage serendipitous conversations. Interviewees reported that team leaders have difficulties in picking up and responding to signals from the group. Further, the event character, the energy, and the creative atmosphere which are characteristic of physical ideation workshops and facilitate emotional contagion among participants cannot be reproduced equally well in a virtual setting, potentially undermining participants' efforts at creative thinking:

"The pure creative thinking is limited because of space, because of the communication medium, because of the reduced playfulness and spark of collaboration that you get when people are in the same room. You just can't replicate that."

(Expert 10)

4.3.2. Outcome of idea generation

Generating a variety of creative ideas is the main goal of ideation workshops. However, as indicated by our findings, the outcomes of such workshops may differ as a function of their setting. That is, the setting may not only affect participants' understanding of the problem to be solved but also their framing of potential solutions. As mentioned earlier, lower psychological distance triggers a more concrete and contextualized form of processing that focuses on the feasibility of achieving a future end state (i.e., *how* things should be done) (Trope and Liberman, 2010). Conversely, higher distance favors a more abstract and decontextualized form of thinking that centers on the feasibility of that end state (i.e., *why* things should be done) (Trope et al., 2007). One direct consequence of these different foci is that physical (virtual) ideation sessions—due to the more (less) contextualized processing they trigger—lead to a greater (lower) number of emerging ideas. As one expert explained:

> "In terms of quantity, certainly. [...] Of course, not every idea can be a brilliant idea, but through the law of large numbers, through the flow, through the quantity, you had a lot more possibilities to build on things and think about them further."
>
> (Expert 9)

Moreover, recognizing the multifaceted character of creativity with respect to the quality, uniqueness, and appropriateness of the ideas, informants often felt that ideas were more abstract and less detailed in virtual formats, as evidenced in the following statement.

> "Even if you encourage people to go into quantity, [...][the ideas] are significantly more high-level, more abstract, less detailed compared to on-site formats."
>
> (Expert 9)

4.3.3. Summary and synthesis of the ideate phase

In sum, the ideate phase is facilitated by intensive interactions between DT participants. In this regard, the structural and social environment in which the ideate phase takes place may serve as an important source of creativity. However, our interviews indicate that these effects cannot be reproduced equally well in virtual settings. As a result, the ideas emerging from the ideate phase tend to be more abstract. Interestingly, these findings align with the DT literature that emphasizes the importance of visualizing ideas to overcome the ambiguity of abstract, verbal explanations (Schweitzer et al., 2016).

4.4. Prototype

The prototype phase focuses on creating prototypes to rework and refine ideas and concepts generated in the previous phase. A key advantage of creating prototypes is that this enables DT participants to visualize and experiment with still unrefined ideas, thereby allowing them to better manage the high levels of uncertainty that are characteristic of this phase (Carlgren et al., 2016). Our interviews point to the potentially positive and negative effects of switching this phase from a physical to a virtual format. On the one hand, virtual innovation environments do not allow participants to haptically explore potential solutions or, in a more figurative sense, to "think with their hands". On the other hand, digital tools afford the opportunity to rapidly modify prototypes across multiple iterations. Both themes are further discussed below.

4.4.1. Touching and thinking with hands

According to EC, cognitive processes are supported through sensorimotor processes such as hand and body movements (Wilson, 2002). As discussed earlier, interacting with tangible objects during the learning process enhances learning performance (De Koning and Tabbers, 2011; Skulmowski et al., 2016). From this perspective, building and interacting with physical prototypes may not only help DT participants in visualizing a concept; their sensorimotor experience may also allow them to understand to what extent a prototype is actually a viable solution. In line with this notion, our informants pointed out that building and interacting with prototypes made it easier for a DT team to achieve a shared understanding and converge on a solution. Put differently, physical engagement was felt to stimulate mental engagement and encourage creative thinking. As one expert remarked:

> "Feedback from people I've worked with and my own thoughts as well, the whole notion of rapid prototyping, having something tangible, and now handing something tangible over to you, not talking about it, but you exploring it, speaking out loud so I understand: that data is limited because you just can't give it to them in that space, which is so crucial to prototyping [...]."
>
> (Expert 10)

As this statement also suggests, the opportunities for thinking with one's hands are significantly restricted in virtual innovation settings. In a similar vein, another expert remarked that digital tools cannot adequately reproduce the experience of physically interacting with a prototype, although such interactions were critical to the success of this phase:

> "These interactions [co-creation, prototyping] are not possible with the current digital tools [...]. And even when VR comes along, VR tools only have limited capabilities. There are just certain sensory factors missing."
>
> (Expert 12)

A direct consequence of this lack of physical interaction with prototypes is that it is harder for DT participants to reach a common understanding. In other words, exchanging and discussing ideas purely through digital means may hinder the process of converging on a jointly created solution. This challenge was pointedly expressed by one expert:

> "So, another example is [...] you talk about it [the prototype] somewhere and everybody has their own idea, but as long as you haven't implemented that into a concrete product or prototype or whatever, different people can have completely different ideas. They'll all say, 'Good idea.', but then when it's implemented, 'Yeah, but that's not what I meant.' I think it's even more difficult in the digital world."
>
> (Expert 2)

At the same time, the interviews also pointed to benefits of switching the prototype phase to a virtual format. As such, modifying physical prototypes across multiple iterations is often an effortful and lengthy process. Digital prototypes, however, can typically be rapidly amended. This is particularly advantageous in the early stages of the prototyping process to quickly learn by obtaining feedback from users. In this context, experts also emphasized that initial low-fidelity prototypes (e.g., digital concept boards or sketches) may already be helpful in discussing the ideas. However, with a rising number of iterations the complexity of the prototype may also increase and thus demand for a stronger physical component. This observation may not only point to a potential trade-off between effectiveness and efficiency when deciding on different prototyping formats but also suggests that the extent to which physical or digital prototyping can be successfully deployed depends on the nature of the specific project. DT projects that are aimed at developing solutions that are predominantly software-based (e.g., an app) may be particularly suitable for digital prototyping. On the other hand, projects that focus on developing tangible products may require a physical prototyping process from the very beginning. As one expert expressed:

> "If it's a product where an app has to be created, it's not a problem at all to work digitally. But if it's a product that has physical components [...], then it's a big problem. It is so much easier when you're in the room to quickly put together some boxes to try out how certain things go."
>
> (Expert 2)

4.4.2. Summary and synthesis of the prototype phase

In the prototype phase, participants benefit from building physical prototypes across multiple iterations. However, our interviews indicate that virtual innovation environments significantly limit the physical and sensorimotor exploration of prototypes, thus curtailing participants' ability to learn from prototypes and achieve a shared understanding with other members of the DT team. At the same time, digital tools may accelerate the development of prototypes, a task that is more difficult to achieve with physical prototypes. These findings may also imply that the effectiveness of physical vs. virtual prototyping is contingent on the extent to which the intended solution is predominantly physical vs. virtual in nature.

4.5. Test

In the test phase, the DT team assesses the prototypes for their practical usefulness, often in direct interaction with end users. Our interviews point to several consequences that result from changing the testing environment from a physical to a virtual setting. First, virtual environments limit the possibilities for users to physically explore prototypes as well as the opportunities for DT teams to fully capture users' reactions to the prototypes. Second, as a result of the increased psychological distance, testing procedures realized in virtual environments tend to become more analytical and goal-oriented. Below, both themes are further discussed.

4.5.1. Interaction possibilities and feedback

Allowing users to interact with prototypes and using their feedback to iterate these prototypes are vital parts of the DT method (Micheli et al., 2019). As our interviews indicate, virtual environments may adversely affect these processes. Similar to the prototype phase, physical exploration enables users to interact with a prototype through multiple senses, thereby simplifying cognitive processing and evaluation (Wilson, 2002). A virtual testing environment, however, limits the potential for physical and sensorimotor exploration and thus reduces the users' ability to process information from the prototype (Foglia and Wilson, 2013). In line with this notion, one expert emphasized the challenges arising from testing a prototype:

> "When testing service prototypes, mock-ups, etc., it's usually relatively similar [between physical and virtual]. Of course, I don't have that haptic experience, as I do when I put something in the hand of someone else and see that first reaction."
>
> (Expert 17)

Virtual testing environments may also restrict the type of feedback that DT teams can collect. As indicated earlier, the physical environment forms an important frame of reference for one's cognitions and behaviors (Wilson, 2002). Hence, fully understanding users' reactions to a prototype may require a full understanding of the environment in which the prototype is tested. Moreover, users' feedback may not only be reflected in their verbal evaluations, but also in their non-verbal responses such as head and body movements. Again, tests conducted in virtual settings may undermine the DT team's ability to pick up on these two types of contextual information, as reflected in the following two statements:

> "When it comes to testing something on-site, we lack the personal aspect of being able to see it in the context of someone's home. Of course, that's what we're missing, and you can't get that from a digital tool."
>
> (Expert 11)

> "The live version [in testing] is much better because you see the reactions of people more strongly and you can read between the lines, better than online."
>
> (Expert 18)

4.5.2. Analytical and goal-driven testing procedure

Another theme that emerged from the interviews was that the type of setting (physical vs. virtual) may affect how the testing process is organized. As elaborated earlier, higher levels of psychological distance will lead people to adopt a more abstract, goal-oriented mindset and to focus less on contextualized, peripheral information (Trope and Liberman, 2000). Interestingly, our informants indicated that testing procedures that are conducted on-site are often affected by idiosyncratic factors that have little to do with the prototypes being tested. In live presentations, for example, members of the DT team may present a prototype very enthusiastically and/or may inadvertently defend a prototype against users' criticisms and thus try to convince users of the idea, which, in turn, may lead to social pressure to affirm ideas and prototypes and consequently to biased judgments regarding a prototype's actual desirability. Virtual testing procedures may be less prone to suffer from such biasing effects, pointing to the interesting possibility that DT teams may discuss a prototype's effectiveness to address a previously identified need in a more analytical and goal-directed manner. These ideas are also summarized in the following statement:

> "Maybe people are more neutral online. [...] If you invite the customer [to test the prototype physically], of course, you may also have someone who presents it very convincingly. And then they [the users] might think, 'Oh, that's cool'. Of course, that's a little more restrained online."
>
> (Expert 14)

4.5.3. Summary and synthesis of the test phase

Our findings suggest that running the testing process in a virtual environment may have both negative and positive consequences. On the one hand, virtual testing procedures make it harder, if not impossible, for users to physically explore a prototype and may thus restrict the amount and richness of feedback that DT teams can gather from such tests. On the other hand, as virtual test environments are likely associated with higher psychological distance, they may be less prone to be affected by idiosyncratic factors such as the specific context of the prototype presentation. Importantly, the extent to which these effects shape the results of the test phase may also depend on the project in question. Projects that focus on software-based innovations may make a more natural fit with virtual test environments as they have fewer physical features (or none at all) relative to hardware- or service-based innovations.

5. General discussion and conclusion

In this research, we aimed to examine how changing from physical to virtual formats affects participants' experiences of the DT process and the outcomes of this process. To this end, we first derived theory-based propositions and then conducted a qualitative study based on 41 interviews with DT experts to further expand on these propositions. Our findings show that the innovation format has a profound influence across all phases of the DT process. As will be discussed next, these findings entail important theoretical and managerial implications.

5.1. Theoretical implications

In the past years, innovation scholars have repeatedly called for strengthening the theoretical foundations of DT and unpacking the individual thought patterns and behaviors involved in DT processes (Eling and Herstatt, 2017; Liedtka, 2015; Wang, 2022). Addressing these calls, we adopt the theoretical lenses of CLT and EC to analyze how the transition from physical to virtual formats affects the process as well as the outcomes of DT projects. This analysis reveals eight overarching themes that are distributed across the different phases of the DT process: (1) emotional immersion into the environment, (2) depth and breadth of user insights, (3) efficiency, goal orientation, and big picture, (4) environment as a source of creativity, (5) outcome of idea generation, (6) touching and thinking with hands, (7) interaction possibilities and feedback, (8) analytical and goal-driven testing procedure. These themes clarify how transitioning from physical to virtual formats affects participants' thought patterns and behaviors, thereby significantly expanding current theorizing on DT.

First, our findings show that the DT format influences how participants process, construe, and interpret information in the different phases of DT projects. Specifically, various of the above-mentioned themes (e.g., emotional immersion, touching and thinking with hands, interaction possibilities and feedback) refer to bodily and emotional immersion into the innovation environment. In line with research on EC (Wilson, 2002),

our study suggests that physical as compared to virtual formats allow for a richer sensory experience across several phases of the DT process (i.e., empathize, ideate, prototype). Put differently, we find that a full psychological immersion may require a full bodily immersion (e.g., Diethelm, 2019; Liedtka, 2020; Rösch et al., 2023; Stephens and Boland, 2015). In addition, another cluster of our overarching themes (e.g., depth and breadth of user insights, efficiency, goal orientation, and big picture) depicts how DT participants analyze and interpret the information gained from their immersion. In line with CLT (Trope and Liberman, 2010), our findings show that virtual settings (which trigger a higher psychological distance) may foster an analytical, goal-driven mindset that enhances efficiency when a great plethora of user insights need to be synthesized. Such a mindset may be especially beneficial in phases where sensorimotor experiences are less prevalent (i.e., define). As these arguments illustrate, our findings contribute to a deeper understanding of individual-level cognitive mechanisms during the DT process (e.g., Auernhammer and Roth, 2021; Liedtka, 2015; Lynch et al., 2021; Thompson and Schonthal, 2020).

Second, our research shows that the cognitive mechanisms triggered by different implementation formats also affect the outcomes generated in different phases of the DT process. Specifically, virtual DT formats yield insights that are of lesser depth and breadth, which, in turn, may lead to ideas that are conceptualized at a higher level of abstraction. While existing research has discussed how DT affects the outcomes of innovation processes, including outcome quality (Seidel and Fixson, 2013), product design (e.g., Beverland et al., 2015; Nagaraj et al., 2020; Zheng, 2018) or product utility (Nagaraj et al., 2020), our research goes beyond these findings and shows that the specific format through which DT projects are implemented may also shape the kinds of outcomes generated through these projects.

Third, our findings extend our understanding of the role of different mindsets in the DT process (Liedtka, 2015; Schweitzer et al., 2016; Thompson and Schonthal, 2020). As such, the mindset that is brought to a task in the DT process needs to be aligned with the task's specific requirements. Tasks that require more rational, convergent thinking—such as identifying a latent need—may be better served by an abstract mindset triggered by higher levels of psychological distance such as in virtual formats. Tasks that necessitate more creative, divergent thinking—such as identifying a comprehensive solution space—may be more effectively aided by a concrete mindset associated with lower levels of distance such as in physical formats. Thus, while abstract or concrete mindsets may be activated by a multitude of factors, our findings identify a particularly important one: the immediate implementation format. In this regard, our findings extend research suggesting that DT approaches problems with both creativity and rationality (Carlgren et al., 2016; Jaskyte and Liedtka, 2022; Stephens and Boland, 2015) by providing a more nuanced understanding of the effectiveness of different implementation formats across different phases of the DT process.

Finally, on a more general level, our findings contribute to calls for a deeper understanding of how to organize innovation activities in the digital age (Rindfleisch et al., 2020; Wetzels, 2021; Zhu and Li, 2023). While digitized innovation activities such as virtual innovation teams are often seen as impediments to the innovation process, our study provides a more nuanced perspective by identifying specific conditions and stages where virtual environments can actually enhance innovation performance.

5.2. Managerial implications

Our study also has important managerial implications. As such, our findings provide a differentiated and nuanced view of the participant experience in virtual innovation environments and identify the opportunities and pitfalls that may be associated with moving DT processes to a virtual format. Of great importance, our findings also clarify that neither physical nor virtual DT formats are inherently superior and that each format features distinct advantages that the other format cannot match to the same extent. Against this background, an ideal DT process may be a hybrid one that combines physical and virtual elements in the most effective manner possible. On the one hand, those phases of the DT process that require a predominantly divergent thinking type and a high degree of interaction with end users or other stakeholders may benefit most from physical formats. On the other hand, phases that necessitate convergent thinking and a more analytical approach may be best realized through virtual formats. Moreover, as each phase of the DT process is composed of different subtasks with different requirements, it is essential to acknowledge the dynamic nature of each phase and recognize the potential for hybrid approaches. As such, DT teams may also be well-advised to combine physical and virtual components within each phase. Next, we discuss the implications of our findings for each phase in more detail.

First, in the *empathize* phase, physical formats may enable DT teams to achieve more profound insights. As such, an accurate understanding of a user's needs, emotions, and motivations may require a physical immersion in the user's environment. Rather than just relying on a user's verbal statements, physically undergoing what the user experiences through all senses may allow DT participants to understand problems that are difficult, if not impossible, to verbalize. In contrast, running the empathize phase purely through virtual formats may run the risk of only achieving an overly abstract, decontextualized understanding of user needs. Despite these challenges, virtual environments also enable more diverse understanding of problems across global distances, reaching a wider audience, and ensuring a greater diversity of perspectives.

Second, in the *define* phase, more abstract mindsets may help DT teams in effectively synthesizing the data collected in the prior phase and in finding meaningful patterns. Such mindsets may be facilitated to a greater extent by virtual settings as such settings are more likely to trigger higher degrees of psychological distance. Hence, virtual settings may allow DT teams to proceed through this phase in a more goal-oriented and analytical manner and to recognize the "big picture" more readily rather than being sidetracked by incidental details.

Third, in the *ideate* phase, the innovation environment can act as an important source of creativity. As such, physical formats allow DT participants to approach the ideation task through all their senses and to more effectively generate rapport with the other team members. As a result, physical ideation sessions may lead to more creative ideas, whereas the ideas generated through virtual sessions may tend to be too abstract to effectively address untapped needs.

Fourth, in the *prototype* phase, building, exploring, and iterating with physical, tangible prototypes may accelerate learning and may enable DT teams to converge on a solution more readily. While virtual prototyping formats are more limited in this respect, they allow for more efficient development of prototypes across multiple iterations. Against this background, the relative efficacy of physical or virtual prototyping may also depend on the extent to which the intended solution is predominantly physical versus virtual in nature.

Fifth, in the *test* phase, on-site testing sessions where both end users and team members are immersed in a natural usage environment may enable DT teams to obtain more meaningful feedback. Again, whereas virtual testing sessions do not allow for a similar degree of immersion, they may be less affected by the idiosyncratic aspects of the testing procedure. Hence, in deciding on the most effective testing format, DT teams may need to carefully weigh these factors against each other and may even combine on-site and virtual testing formats.

In sum, our findings show that neither physical nor virtual DT processes are all-purpose weapons. Instead, hybrid DT processes where physical and virtual formats are aligned with the requirements of the individual DT process phases are likely to lead to the most effective solutions. In this regard, our research may help managers by clarifying the strengths and limitations of physical and virtual formats and by providing a roadmap for designing hybrid DT processes. Fig. 1

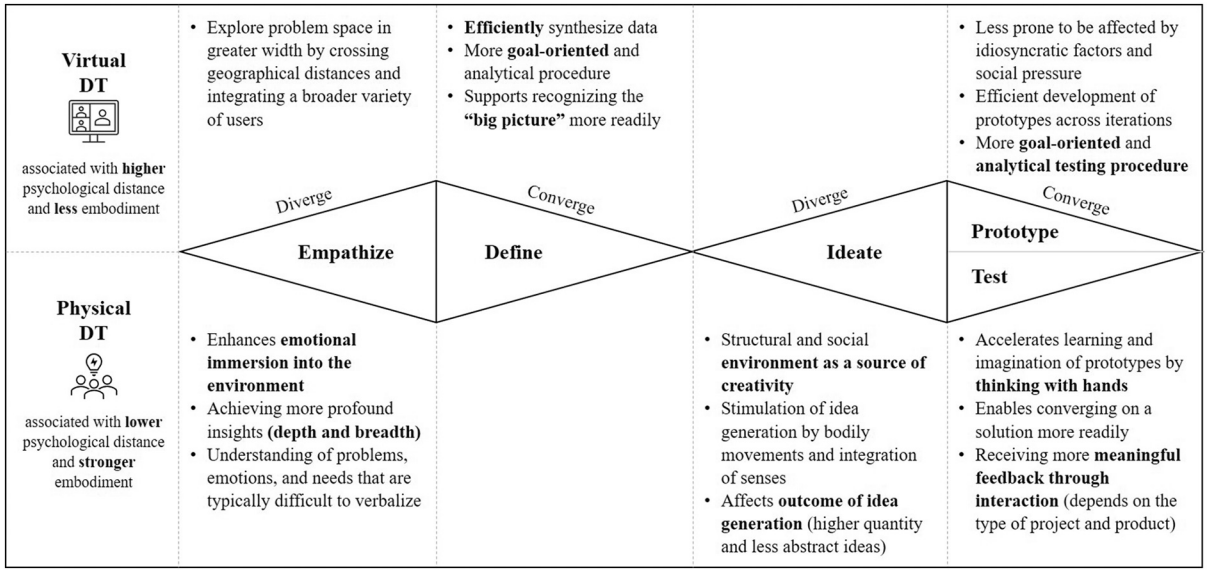

Fig. 1. Summary of findings and considerations for practice.

summarizes the relative benefits of physical and virtual formats across the phases of the DT process, providing practitioners with actionable insights for the effective design of DT workshops.

5.3. Limitations, future research, and conclusion

Our study also has limitations that call for future research. First, we focused on the process-based character of DT as well as the mindsets that characterize this process. However, DT can also be considered as a method consisting of unique tools and techniques (Micheli et al., 2019). Hence, future research may examine in more detail which tools are more suitable for on-site or virtual settings and/or how tools originally developed for on-site settings may need to be adapted for virtual settings. In doing so, future studies may also rely on different methodological paradigms. For instance, to test the effect of physical and virtual formats on idea generation, one could design an experiment in which participants work on specific creative tasks, either physically or with the support of virtual tools, and compare the ideas generated through these different processes (Brucks and Levav, 2022). Alternatively, matching employee surveys with actual performance data would allow for assessing the relative effectiveness of physical and virtual DT projects.

Second, our study was focused on analyzing the impact of changing DT processes from a physical to a virtual setting based on the individual participant. However, a central aspect of the DT methodology is its collaborative nature. Given that DT projects unfold within team frameworks rather than in isolation, the interplay between individual and team contributions is a promising avenue for future research. This nuanced exploration may contribute to our understanding of the possibilities and challenges of virtual DT processes and extend our findings to the broader discourse of team collaboration. In addition to the individual performance of DT activities, teamwork also involves a social process of interacting with other people and sharing concepts, knowledge, and experiences, which may be particularly relevant for fostering creativity (Aissa et al., 2022).

Third, our findings suggest that the extent to which virtual DT methods can be deployed successfully may also depend on the extent to which the solution to be developed is more physical or digital in nature. Future research may explore such contingency-related factors in more detail. For instance, smart products combine both material and digital components (Raff et al., 2020). Here, it may be interesting to examine if the different components of smart products (material, digital components) can be developed across different workstreams (physical and virtual) or if DT processes focused on smart products will need to consider the interplay between material and digital components from the very beginning. Another contingency that future research may want to consider is the type of prototyping. Virtual DT might be better suited for low-fidelity prototyping due to the ease of sketching or modification, while physical DT could be more appropriate for high-fidelity prototyping when it comes to representing the final product.

Fourth, we assumed that there is a natural alignment between different innovation formats and psychological distance. At the same time, past research has shown that people's natural perceptions of psychological distance can be altered. For instance, asking individuals to engage in different types of mental simulation (i.e., the imitative mental representation of an event) changes their psychological distance to a product prototype, regardless of the objective distance of the prototype (Rose et al., 2021). Similarly, technological tools like virtual, augmented, or mixed reality may allow people to have experiences that parallel bodily experiences (Hilken et al., 2017). Arguably, empathy and a comprehensive understanding of users' needs may be improved through sensory-enhanced virtual spaces, thereby overcoming the limitations potentially associated with digital innovation environments (Hennig-Thurau et al., 2022).

Last, the infusion of (generative) AI may significantly alter innovation processes in the future (Bouschery et al., 2023; Füller et al., 2022); thus, AI tools may also potentially create a shift in some of our identified patterns. For example, generative AI bears the potential to erode some of the advantages attributed to physical formats, such as offering a diverse range of perspectives and drawing inspiration from the surroundings. Thus, future research may examine the degree to which the incorporation of generative AI modifies our findings.

In closing, by examining and contrasting participants' experiences in both physical and virtual DT processes and embedding these experiences in a broader theoretical foundation, this research enhances our understanding of the DT process. As the digitization of the workplace in general and of innovation processes in particular is likely to further increase in the future, we hope that our study will stimulate further research along these lines.

CRediT authorship contribution statement

Alice Minet: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Daniel Wentzel:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis,

Conceptualization. **Stefan Raff:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Janina Garbas:** Writing – review & editing, Validation, Supervision, Investigation.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techfore.2024.123596.

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