JACOBS UNIVERSITY

Performing Design Thinking Virtually – A Socio-Cognitive View on Virtual Design Thinking

By

Beke Marie Redlich

a Thesis submitted in partial fulfillment
of the requirements for the degree of

Doctor of Philosophy
in Business Administration

Approved Dissertation Committee

Prof. Dr. Christoph Lattemann
(Jacobs University Bremen)

Prof. Dr. Olivier Berthod
(Jacobs University Bremen)

Prof. Dr. Susanne Robra-Bissantz
(Technische Universität Braunschweig)

Date of Defense: 20.11.2019

Business & Economics

I Statutory Declaration

Family Name, Given/First Name	Redlich, Beke Marie
Matriculation number	20331915
What kind of thesis are you submitting	PhD-Thesis

English: Declaration of Authorship

I hereby declare that the thesis submitted was created and written solely by myself without any external support. Any sources, direct or indirect, are marked as such. I am aware of the fact that the contents of the thesis in digital form may be revised with regard to usage of unauthorized aid as well as whether the whole or parts of it may be identified as plagiarism. I do agree my work to be entered into a database for it to be compared with existing sources, where it will remain in order to enable further comparisons with future theses. This does not grant any rights of reproduction and usage, however.

The Thesis has been written independently and has not been submitted at any other university for the conferral of a PhD degree; neither has the thesis been previously published in full.

German: Erklärung der Autorenschaft (Urheberschaft)

Ich erkläre hiermit, dass die vorliegende Arbeit ohne fremde Hilfe ausschließlich von mir erstellt und geschrieben worden ist. Jedwede verwendeten Quellen, direkter oder indirekter Art, sind als solche kenntlich gemacht worden. Mir ist die Tatsache bewusst, dass der Inhalt der Thesis in digitaler Form geprüft werden kann im Hinblick darauf, ob es sich ganz oder in Teilen um ein Plagiat handelt. Ich bin damit einverstanden, dass meine Arbeit in einer Datenbank eingegeben werden kann, um mit bereits bestehenden Quellen verglichen zu werden und dort auch verbleibt, um mit zukünftigen Arbeiten verglichen werden zu können. Dies berechtigt jedoch nicht zur Verwendung oder Vervielfältigung.

Diese Arbeit wurde in der vorliegenden Form weder einer anderen Prüfungsbehörde vorgelegt noch wurde das Gesamtdokument bisher veröffentlicht.

....

Date, Signature

II Foreword

My personal and intrinsic motivation that underlies this dissertation is concerned with a desired increase of creative working in business areas that are originally not associated with it other than distinct artistic or design professions. Whereas creativity can refer to an individual, it is also allied with collaboration and co-creation. Taking over the perspective of multiple people, who commonly collaborate in a creative manner by sharing one intention and yielding new solutions, requires an appropriate environment and structure when it comes to business operations.

Thankfully, I am not alone with this standpoint and therefore, it was more than a lucky coincidence that a team of scientists and practitioners, which I joined, developed the idea of introducing and adapting the creative innovation development approach Design Thinking for an application in small- and medium sized companies. But there is more to 'only' adapting appropriate on-site creative innovation approaches in a globalized business ecosystem – creative working in a systemized way, as it is performed in Design Thinking, needs to be applicable in virtual settings. Companies and people are dispersed but Information- and Communication Technology is able to overcome the barrier of location. Following, the second major motivation of this dissertation refers to virtually performing creative work collaboratively in the manner of Design Thinking. Information Systems that inherit the needs of people and the appropriate means of technology yielding toward a certain collaboration style are necessary and therefore the research focus of this contribution.

Any work situation is better if someone is surrounded by a highly motivated and diverse team of colleagues that is institutionally supported in a project environment. Being a member of the DETHIS-Team as project coordinator and research associate, offered me an ultimate on-site and virtual collaboration environment where the people live what they advertise. Hence, this cumulative dissertation with the title 'Performing Design Thinking Virtually – A Socio-Cognitive View on Virtual Design Thinking' was carried out as part of the joint research project 'DETHIS – Design Thinking for Industrial Services' funded by the German Federal Ministry for Research and Education (BMBF; Grant 02K14A140). The dissertation was conducted at Jacobs University's Department of Business & Economics at the chair of Prof. Dr. Christoph Lattemann specialized on Innovation Management and Information Systems. The conducted research is dedicated to increase creative and satisfying working modes as well as innovation in a globalized business world.

III Abbreviations

Action Design Research	ADR
Action Research	AR
Augmented Reality	AuR
Forum for Aviation Research	IFAR
German Federal Ministry of Research and Education (Bundesministerium für Bildung und Forschung)	BMBF
German National Aeronautics and Space Research Center (Deutsches Zentrum für Luft- und Raumfahrt)	DLR
Building, Intervention, and Evaluation	BIE
Computer-Mediated-Communication	CMC
Computer-Supported Cooperative Work	CSCW
Control Group	CG
Creativity Support Index	CSI
Creativity Support Tool	CST
Design Science	DS
Design Science Research	DSR
Design Thinking	DT
Experimental Group	EG
Information- and Communication Technology	ICT
Information Systems	IS
Information Technology	IT
Innovation Management	IM
Jacobs University Bremen	JUB
Media Naturalness Theory	MNT
Media Richness Theory	MRT
Media Synchronicity Theory	MST
Research and Development	R&D
Shared Mental Models	SMM
Technical University Braunschweig	TUBS
User Experience Design	UX
User Interface Design	UI
Virtual Design Thinking	VDT
Virtual Reality	VR

IV List of Figures

V List of Tables

VI Abstract

In today's world, corporate teamwork is increasingly characterized by co-creation and dispersed stakeholders that need to collaborate for specific purposes, such as innovation development (Frow et al. 2015, Yoo 2013). The dispersed setting of team members motivates a virtual instead of an on-site performance of teamwork to increase the possibility of uniting multiple and suitable stakeholders for specific tasks, while reducing the efforts to commonly be in the same place at the same time (Lipnack and Stamps 1999). To meet the needs of a contemporary, systematic procedure for Innovation Management (IM) in a globalized world, the collaborative and co-creative innovation development approach Design Thinking (DT) needs to be facilitated toward a virtual performance (Furmanek and Daurer 2019, Gräßler et al. 2017, Gumienny et al. 2011).

In order to prepare the foundation for a suitable so-called Virtual Design Thinking (VDT) approach, an in-depth examination of commonly analog-performed DT needs to be conducted and its underlying principles identified. The examinations on DT enable to further investigate how the innovation development approach can be applied on a virtual level or how the VDT experience can be improved over the analog performance. This undertaking needs to be accompanied by measurements that indicate the success of the VDT performance in adhering to a socio-cognitive view on effectiveness (Gilson et al. 2015, Hjørland 2002).

Virtual teamwork settings are new to companies, employees, and customers and specific collaboration modes require suitable Information and Communication Technology (ICT) (Gilson et al. 2015). Next to many other business areas, IM is challenged by virtual collaboration settings (Lurey and Raisinghani 2001). To build a ground for supporting virtual collaboration for innovation development, already established analog approaches can be employed as a focal point for designing a positive virtual teamwork experience. It is therefore crucial to find suitable approaches for designing virtual team performance that support the development of innovative products, services, and processes. Whereas in the past, rigid and engineering-imprinted models were applied for IM, approaches that employ creative, iterative working modes and that take user-centeredness into account, such as DT, are nowadays referred to as appropriate (Prud'homme van Reine 2017).

DT has evolved as a successful analog approach and can be specified as a human-centered approach to innovation development based on creativity and problem-solving on the manner designers think and act (Brown 2008, 2009, Carlgren, Rauth, et al. 2016, Martin 2009). The approach strongly relies on hands-on, face-to-face collaboration as well as a physical workspace that is shaped and coined by DT teams (Brenner et al. 2016, Meinel and Leifer 2012). DT is a systematic and holistic approach that consists of three elements – DT process, DT methods, and the DT mindset – and the working mode is inherently based on collaboration, co-creation, creativity, and visualization (Brenner et al. 2016, Carlgren, Rauth, et al. 2016, Leavy 2012).

With the aim of this dissertation to enable VDT, which focuses on a collaborative process-perspective, the application of mere qualitative or quantitative research methods miss out the underlying user-centered and action-based problem context. Thus, the mixed-methods research methodology Action Design Research (ADR) was applied, which deploys practical, recurring, and meaningful interventions to gain insights regarding the collaboration of multidisciplinary teams in a process of improving Information Systems (IS) in a corporate problem context from a user-centered perspective (Sein et al. 2011, Veling et al. 2016). The action-inspired interventions allow for the examination of the underlying principles of the analog approach by steadily introducing an increasingly ICT-based performance in a virtual environment. The emerging ensemble artifact,

the VDT approach, mirrors an improved setting of a given corporate problem context based on real-life experiences, which allows for an examination of socio-cognitive effects on the VDT performance and, thus, leads to receiving the objectives of this cumulative PhD-thesis (Purao et al. 2013). As a result, this dissertation presents an applicable VDT approach for companies that is perceived as satisfying and effective by the team members.

VII Zusammenfassung

Im unternehmerischen Kontext ist Teamarbeit heutzutage zunehmend durch Ko-Kreation und verteilte Anspruchshalter, die für eine gemeinsame Aufgabe kollaborieren wie beispielsweise der Innovationsentwicklung, geprägt (Frow et al. 2015, Yoo 2013). Vor dem Hintergrund örtlich verteilter Teammitglieder wird virtuelle vor analoger Zusammenarbeit in zunehmendem Maße bevorzugt. Dies wird motiviert durch einen geringeren Aufwand mehrere, geeignete Anspruchshalter für bestimmte Aufgaben zur gleichen Zeit an den gleichen Ort zusammenzubringen (Lipnack und Stamps 1999). Design Thinking (DT) ist ein kreativer, kollaborativer Ansatz zur Entwicklung von Innovationen, der bis dato klassisch analog und ortsgebunden angewendet wird (Furmanek und Daurer 2019). Um den unternehmerischen Anforderungen nach einem dem Zeitalter der Globalisierung entsprechenden systematischen Innovationsentwicklungsansatz Rechnung zu tragen, sollte DT auch in einem virtuellen Umfeld durchführbar sein (Furmanek und Daurer 2019, Gräßler et al. 2017, Gumienny et al. 2011). Ziel dieser Arbeit ist es, Virtuelles Design Thinking (VDT) zu ermöglichen.

Um eine Grundlage zur Entwicklung eines geeigneten VDT-Ansatzes zu schaffen, muss der ganzheitliche, üblicherweise analog durchgeführte DT-Ansatz betrachtet und die zu Grunde liegenden Prinzipien identifiziert werden. Die Auseinandersetzung mit DT ermöglicht daraufhin herauszufinden, wie der Innovationsentwicklungsansatz in einer virtuellen Umgebung angewendet oder wie durch den Einsatz passender Informations- und Kommunikationstechnologien (IKT) das VDT-Erlebnis über das analoge Verfahren verbessert werden kann. Dieses Vorhaben muss durch eine adäquate Erfolgsmessung begleitet werden, die im Kontext von VDT einer sozio-kognitiven Perspektive auf Effektivität folgt (Gilson et al. 2015, Hjørland 2002).

Für viele Unternehmen, Mitarbeitende und Kunden ist die Möglichkeit und Notwendigkeit virtuell zusammenzuarbeiten noch neu. Gleichzeitig braucht es passende Ansätze der virtuellen Kollaboration, die Nutzende in ihren spezifischen Tätigkeiten unterstützen (Gilson et al. 2015). Hiervon ist auch das Innovationsmanagement (IM) betroffen (Lurey und Raisinghani 2001). Bereits etablierte Ansätze zur Innovationsentwicklung können als Ausgangspunkt verwendet werden, um positive Erfahrungen einer virtuellen Kollaboration zu gestalten und dabei Nutzende zu unterstützen. Dies erfordert die Identifizierung eines etablierten Ansatzes zur Entwicklung von innovativen Produkten, Dienstleistungen und Prozessen, der auch virtuell durchgeführt werden kann. In der Vergangenheit lag der Fokus bei Innovationsentwicklungsansätzen oftmals auf ingenieurswissenschaftlich geprägten Modellen, wobei heutzutage eher kreative, iterative und nutzendenzentrierte Ansätze als zeitgemäß eingestuft werden – hierzu zählt auch DT (Prud'homme van Reine 2017).

Analog durchgeführtes DT wurde bereits als adäquater und erfolgsversprechender Innovationsentwicklungsansatz identifiziert, der maßgeblich auf interaktive, persönliche Zusammenarbeit in Teams, die in physischen Innovationslaboren gemeinsam interagieren, basiert (Carlgren, Rauth, et al. 2016). DT wird als ein humanzentrierter, kreativer und problembasierter Innovationsentwicklungsansatz spezifiziert, der auf der Art und Weise beruht, wie Designer denken und handeln (Brown 2008, 2009, Martin 2009). DT ist weiterhin ein systematischer und ganzheitlicher Ansatz, der sich aus drei Elementen zusammensetzt (DT Prozess, DT Methoden und DT Mindset), wobei der Arbeitsmodus im DT geprägt ist durch Kollaboration, Ko-Kreation, Kreativität und gemeinsames Visualisieren (Brenner et al. 2016, Carlgren, Rauth, et al. 2016, Leavy 2012).

Mit dem Fokus auf einer prozessbezogenen Perspektive auf virtuelle Kollaboration im DT, ist die Evaluation durch rein quantitative oder qualitative Methoden nicht zielfördernd, da diese den aktionsbasierten Kontext und die Perspektive der Nutzenden nicht ausreichend abbilden können. Deswegen wurde im Rahmen dieser Dissertation eine Kombination aus quantitativen und qualitativen Vorgehensweisen in der Anwendung von Action Design Research (ADR) ausgewählt (Sein et al. 2011, Veling et al. 2016). Zur Erkenntnisgewinnung von Problemsituationen, denen eine Zusammenarbeit von multidisziplinären Teams zu Grunde liegt, werden im ADR wiederkehrende, praktische und aussagekräftige Interventionen mit dem Ziel durchgeführt, eine positive Veränderung für Nutzende im Kontext von Unternehmen und Informationssystemen zu erreichen. Der aktionsbasierte Anteil der Gestaltungsforschung in ADR ermöglicht die Identifizierung und Berücksichtigung des ganzheitlichen DT-Ansatzes und seiner Prinzipien, welcher sukzessiv mit Hilfe von IKT zunehmend virtuell durchgeführt wird. Das entstehende Ensemble Artefakt, der VDT-Ansatz, spiegelt dabei die zunehmend verbesserte Situation im unternehmerischen Kontext durch reale Interventionen wider, welches die Betrachtung von sozio-kognitiven Auswirkungen bei der Ausführung von VDT und somit die Zielerreichung dieser kumulativen Promotion ermöglicht (Purao et al. 2013). Als Ergebnis präsentiert diese Dissertation einen für Unternehmen anwendbaren VDT-Ansatz, der von den Nutzenden als zufriedenstellend und effektiv empfunden wird

VIII Table of Contents

1. Introduction and Motivation

Design Thinking (DT) is a creative innovation approach for the purpose of developing products, services, and processes, which is performed collaboratively in teams in an on-site setting (Dunne 2018, Martin 2009, Schmiedgen et al. 2016). The innovation approach strongly relies on hands-on, face-to-face collaboration as well as a physical workspace that is shaped and coined by DT teams (Brenner et al. 2016, Carlgren, Rauth, et al. 2016, Meinel and Leifer 2012). This dissertation presents an in-depth examination on how DT can be performed virtually, while adhering the underlying principles of the creative innovation approach and applying a socio-cognitive view on effectiveness.

DT is described as a human-centered approach to innovation development that is performed in a creative teamwork setting and applies a problem-solving perspective that stems from the way designers think and act (Brown 2008, 2009, Carlgren, Rauth, et al. 2016, Martin 2009). DT has its origin in Design Science (DS) and design practice and was introduced as an Innovation Management (IM) approach in the early 2000s. Consequently, DT research is a comparably young area of interest and different to approaches that were originally developed scientifically at first, such as the stage-gate-model (Cooper 1990), DT was introduced in practice and science at almost the same time.

The state of the art research on DT agrees upon a stringently designed approach that inherits three elements: a process model made out of single steps (DT process) in which DT methods are performed that match the predefined problem statement and a DT mindset that complements the overall approach (Brenner et al. 2016). The DT mindset can be specified as a combination of attitudes such as open-mindedness, bias toward action, and being empathetic, as well as working modes like collaboration, co-creation, creativity, and visualization, that commonly support innovation development in DT (Brenner et al. 2016, Carlgren, Rauth, et al. 2016, Dosi et al. 2018). Furthermore, the performance of DT can be characterized as a complex collaboration mode. Ultimately, the application of DT led to innovative products, services, and processes in companies such as Toyota, IBM, and Intuit (Liedtka et al. 2013). Derived from past research, the following understanding of DT underlies this dissertation (Brenner et al. 2016, Carlgren, Rauth, et al. 2016, Johansson-Sköldberg et al. 2013, Kimbell 2011):

> *DT is understood as a systematic, multidisciplinary, creative, and user-centered approach for the development of innovations such as products, services, and/or processes that is inherently based on teamwork and it consists of three equivalent elements that are the DT process, methods, and mindset, which jointly constitute the DT approach.*

A major challenge for companies to using and constantly implementing DT for their innovation purposes stems from its location-dependence (Fischer et al. 2019). Performing DT in its analog version usually requires the presence of several team members, who can be employees, customers, and other experts, as well as a DT coach that accompanies the team. The effort of being in the same place, commonly innovation labs, in concurrent periods of days and months opposes today's business environments that are dispersed or even globalized. Due to dispersed settings, corporate teamwork is increasingly performed virtually (Gilson et al. 2015, Lipnack and Stamps 1999, Yoo 2013). Corporate virtual teamwork settings in general are new for a great number of companies, employees, and customers, and specific collaboration modes require suitable information and communication systems, which also applies for IM (Lipnack and Stamps 1999, Yoo 2013).

Since there are no originally designed virtual innovation development approaches (Gilson et al. 2015), established analog approaches can be employed as a focal point for designing a positive virtual collaboration experience. In the past, innovation development approaches were considered appropriate that are rigid and engineering-imprinted, today's IM refers to creative, iterative, and user-centered approaches as suitable, such as DT (Prud'homme van Reine 2017).

Whereas the choice for a suitable innovation approach is influenced by IM research, another aspect to decide upon is the focus when virtualizing DT. While looking at the status quo on research regarding Virtual Design Thinking (VDT), it becomes apparent there are only a few scientific studies existent. Although past work on VDT outlines the importance and necessity to perform DT virtually, none of the solutions led to a lasting VDT approach implemented in a variety of companies (Gräßler et al. 2017, Gumienny et al. 2011, Rive and Karmoker 2016, Wenzel et al. 2016). A review on given VDT approaches shows that there are at least three different perspectives on how to tackle the objective of performing DT virtually. One perspective examines VDT from a technological viewpoint by developing artifacts based on the application of new technology to create a communication infrastructure (Gericke et al. 2014, Gräßler et al. 2017). Another perspective focuses on specific aspects of the overall DT approach such as specfic DT methods or phases to examine the virtualization in-depth (Potthoff et al. 2018, Siemon et al. 2018). A third perspective refers to virtualizing the holistic DT approach by applying a process- and performance perspective as well as focusing on a socio-cognitive evaluation (Furmanek and Daurer 2019, Rao 2018); this perspective is subject of this dissertation.

Subsequently, the underlying research questions of this dissertation are:

- *How can the DT approach be applied or be improved in a virtual setting with regard to DT process, methods, and mindset as well as the basic principles?*
- *How can the effectiveness of virtually performed DT be measured with regard to the adherence of the holistic DT approach from a socio-cognitive perspective?*

Approaching the research questions from a scientific disciplines' point of view inherits the challenge of an interdisciplinary-motivated undertaking. DT can be deduced from a historically-grown development within DS and practice that has been transferred to management studies, especially to IM (Carlgren et al. 2014, Johansson-Sköldberg et al. 2013, Kimbell 2011). Furthermore, the intention to virtualize DT requires the localization of this research within the field of Information Systems (IS), especially Human-Computer-Interaction (HCI) and Computer-Supported Cooperative Work (CSCW) due to the inherent collaborative nature of performing DT. Human- and user-centeredness call for the examination of individuals and teams that interact with each other via Computer-Mediated-Communication (CMC). This implies the integration of psychologically-driven theories and evaluation approaches within this dissertation in order to understand the collaborative working modes that exist in DT to enable a satisfying virtual performance (Hjørland 2002). Following, this work is situated in the intersection of IS, DS, and IM, and applies a socio-cognitive view deriving from the discipline of psychology.

From a research methodology point of view, applying a mere qualitative or quantitative research methodology would miss out the underlying process- and performance perspective as well as the user-centered and action-based problem context of virtual collaboration for innovation purposes with DT. To examine how DT can be performed virtually requires actual DT teams, a problem context, and the performance of VDT. To evaluate VDT in terms of effectiveness from a socio-cognitive view requires appropriate measures. Thus, the mixed-methods research methodology Action Design Research (ADR) is applied in this dissertation. ADR is a combined methodology of Design Science Research (DSR) and Action Research (AR), which utilizes practice-inspired and recurring interventions to gain insights regarding the collaboration of diverse teams in a process of improving an IS and corporate problem context with a user-centered focus (Sein et al. 2011, Veling et al. 2016). The action-inspired interventions allow for the identification of the underlying principles of the analog approach at first and, accordingly, with increasing virtual performance with ICT tools, an evaluation of the VDT performance from a stakeholder perspective is possible. An emerging ensemble artifact resembles an improved setting of a given corporate challenge based on real-life experiences. The ensemble artifact is the process and the result of a user-centered approach that inherits the people, the corporate- and IS context, which leads to designing a desired performance and ICT environment at the same time (Purao et al. 2013). Following, the output of ADR includes an Information Technology (IT) artifact in a social context but is not limited on a 'tool view' (Orlikowski and Iacono 2001, Purao et al. 2013). The targeted aim of an ensemble artifact allows for an examination of socio-cognitive effects on the VDT performance (Almefelt et al. 2003, Purao et al. 2013).

The performance of ADR in this dissertation is embedded in a joint research project, of which one goal represents the aim of this dissertation. Whereas the overall research methodology is ADR, the single research papers that were conducted to approach the research questions (chapter 6-10) apply DSR. It is the holistic examination of the single studies, with the institutionalized problem context of the joint research project, as well as the theoretical background (chapter 2) that together form the ADR approach as such.

This dissertation provides the reader with a holistic viewpoint on the virtualization of DT. Besides the in-depth presentation of joint spheres between DS, IS, and IM, the state of the art of research on DT is outlined to understand the basic principles to virtualize DT in a human-centered manner. The theoretical background and the single research papers reveal that it is worthwhile to examine VDT from a process-, performance-, and socio-cognitive perspective to create an approach of which the performance is satisfying for its users. The reader will learn that it is generally possible to virtualize DT and that hybrid forms – a combination of analog and virtual DT – as well as fully virtually performed DT can be almost as satisfying as its on-site version.

Moreover, the human-centered evaluation approach for DT can be deployed by given psychology-rooted theories, constructs, and effects that help to understand why satisfaction and perceived effectiveness of teams are an essential aspect when designing IS for virtual collaboration regarding specific corporate purposes such as IM. The pursued work provides several connecting points for future research ambitions. Additionally, the general conclusions of this contribution outline that science and practice can benefit from the developed VDT approach.

The following subsection 1.1 provides an overview of the structure of this dissertation including the organization of theoretical backgrounds that underlie the single research papers in order to guide the reader through this contribution.

1.1 Structure of the Dissertation

The state of the art on, as well as the aim to virtualize DT is influenced by three research areas, namely IS, DS, and IM. The three areas inherit their own definitions of terms, amongst others 'design' or 'artifact', which need to be demarcated and defined in the context of this dissertation to prevent confusion. Furthermore, the root of DT provides links to the three research areas from a theoretical perspective that imply consequences for the undertaking of creating a VDT approach. Ultimately, the state of the art of DT is more complex as it might seem when taking a closer look. This initial situation informs the structure of the theoretical background (chapter 2), where at first a context-specific presentation of IS and DT is presented (subsection 2.1), followed by an examination of DS and DT where the conceptual roots and discourse toward the establishment of DT are outlined (subsection 2.2). Chapter 2 closes the theoretical background with an examination of IM and DT (subsection 2.3).

The theoretical background fuses into the state of the art on DT (chapter 3), where the concept is outlined as well as the underlying principles introduced, which were applied as a basis for the single studies (see figure 1). Chapter 1-3 is the foundation for the detailed presentation of the research gap and questions, which are introduced in chapter 4. Chapter 5 presents the research methodology of this dissertation, by firstly presenting ADR and the underlying framework as well as the description of the detailed procedure on how ADR was conducted for this dissertation. The choice for ADR is justified by the presented theoretical background, the state of the art on DT as well as the localization of this study within IS, DS, and IM.

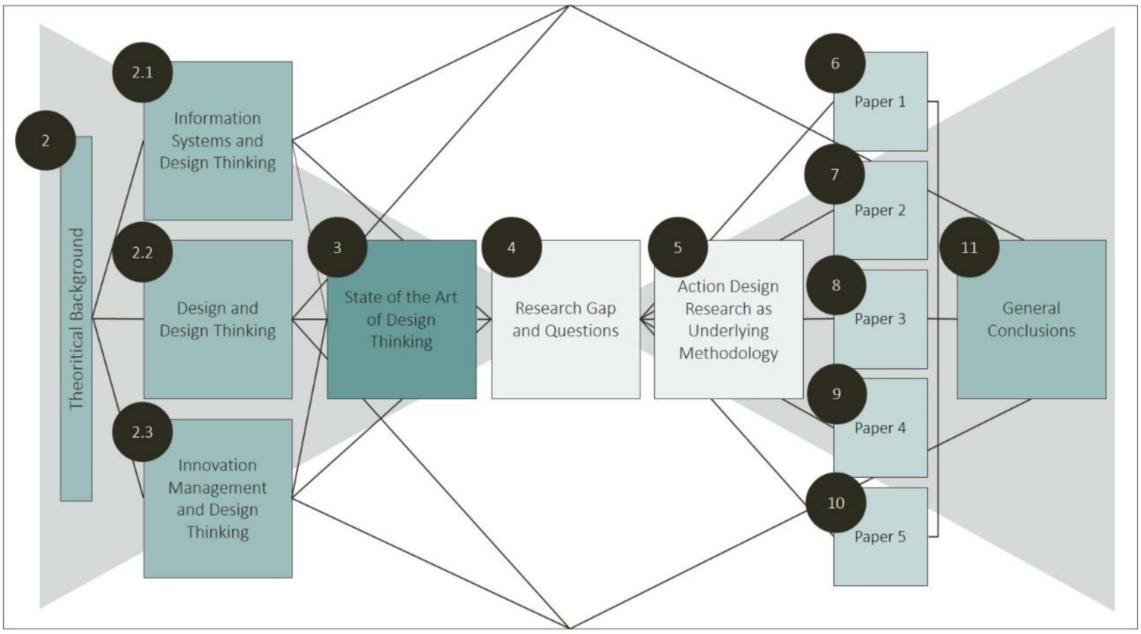

Figure 1 Structure of the dissertation

The chapters 1-5 serve as the introduction of the single research papers, which are individually presented in chapters 6-10, as part of this cumulative dissertation. A brief summary of the single research papers follows in the next subsection 1.2. This contribution closes with a general conclusion that inherits a summary of the results, the limitations, and the implications for research and practice as well as an outlook and final remarks (chapter 11).

1.2 Summary of the Single Research Papers

As part of the cumulative dissertation approach, five research papers were collaboratively developed that all serve the objective to respond to the research questions. All articles reflect on different aspects with regard to virtualizing the DT approach. Figure 2 gives an overview of the papers, including authors, title, publication channel, and ranking.

Paper No. / Authors / Title	Publication type	Status	Ranking*
Paper 1			
Authors: **Redlich, B.**, Siemon, D., Lattemann, C., Robra-Bissantz, S.			
Shared Mental Models in Creative Virtual Teamwork	Hawaii International Conference on System Sciences (HICSS)	Published 2017	C
Paper 2			
Authors: Siemon, D., **Redlich, B.**, Lattemann, C., Robra-Bissantz, S.			
Forming Virtual Teams – Visualization with Digital Whiteboards to Increase Shared Understanding, Satisfaction and Perceived Effectiveness	International Conference on Information Systems (ICIS)	Published 2017	A
Paper 3			
Authors: Lattemann, C., Siemon, D., Dorawa, D., **Redlich, B.**			
Digitization of the Design Thinking Process Solving Problems with Geographically Dispersed Teams	Human Computer Interaction (HCI)	Published 2017	C
Paper 4:			
Authors: **Redlich, B.**, Dorawa, D., Siemon, D., Lattemann, C.			
Towards Semi-Virtual Design Thinking – Creativity in Dispersed Multicultural and Multidisciplinary Innovation Project Teams	Hawaii International Conference on System Sciences (HICSS)	Published 2018	C
Paper 5:			
Authors: **Redlich, B.**, Lattemann C., Fischer S.			
Can Virtual Design Thinking Be Performed Satisfyingly?	-	-	-
*Ranking based on VHB ,Teilrating Wirtschaftsinformatik' http://vhbonline.org/vhb4you/jourqual/vhb-jourqual-3/teilrating-wi/			

Figure 2 Overview of research papers 1-5

The work titled 'Shared Mental Models in Creative Virtual Teamwork' (Chapter 6) presents an experiment in which the influence of collaborative virtualization on the building of Shared Mental Models (SMM) with regard to tackling wicked problems is examined and reflected in the light of team creativity (Redlich et al. 2017). This study sheds light on specific cognitive requirements of the DT approach and thereby concentrates on the necessity to create a shared understanding, which is firstly challenged by wicked problems and, secondly, by a virtual collaboration with the help of a digital whiteboard (Buchanan 1992, Martins and Shalley 2011, Maynard and Gilson 2014). Here, the psychological construct of SMM is introduced and applied for measuring the effect on perceived satisfaction, effectiveness, and performance requirements, which created a possible path for the evaluation of a VDT approach (de Vreede et al. 2012).

In chapter 7, the study titled 'Forming Virtual Teams – Visualization with Digital Whiteboards to Increase Shared Understanding, Satisfaction and Perceived Effectiveness' advances the findings from the previous chapters' study by examining virtual team effects with regard to the teamwork phase model by Tuckman (1965) and Tuckman and Jensen (1977) 'Norming', 'Forming', 'Storming', 'Performing', and 'Adjourning' (Siemon et al. 2017). Furthermore, this study presents and compares the results of an experiment with regard to media theories – Media Naturalness-, Media Synchronicity-, and Media Richness Theory – in order to appraise the results with overarching insights and to derive future directions from the findings (Daft and Lengel 1986, Dennis et al. 2008, Kock 2004). As a result, this study shows how the use of a virtual tool for collaborative visualization positively effects cognitive processes and thereby helps to understand requirements that are necessary for performing a whole DT approach virtually.

Whereas the first two studies deal with specific parts of a DT approach – team formation, virtual visualization, and wicked problems – the third study (chapter 8) addresses the development of an artifact that is based on given ICT tools to reproduce a complete DT process (Lattemann et al.

2017). 'Digitization of the Design Thinking Process – Solving Problems with Geographically Dispersed Teams' concentrates on formal DT process requirements and specific communication channels that are necessary to enable VDT in general.

The insights from Redlich et al. (2017), Siemon et al. (2017), and Lattemann et al. (2017) flow into another working cycle and experiment that examined the performance of a semi-virtual DT workshop and measured the perceived level of satisfaction and effectiveness compared to an analog DT workshop. In 'Towards Semi-Virtual Design Thinking – Creativity in Dispersed Multicultural and Multidisciplinary Innovation Project Teams' (Chapter 9), the results of a survey based on SMM, compared to given media theories, were additionally accompanied by examining specific functionalities within the collaborative performance of virtual visualization on a digital whiteboard (Redlich, Dorawa, et al. 2018). Thus, each study presents insights that, on the one hand, respond to the underlying principles of the overall DT approach as well as virtualizing it and, on the other hand, establish a human-centered approach and socio-cognitive view on how to measure the effectiveness of VDT.

Chapter 10 presents the closing study, which deals with the presentation of a complete VDT approach and its evaluation. Several virtually performed DT workshops are presented with regard to their conceptualization and resulting effects of the team members. Moreover, this study introduces a psychological effect – the McGurk Effect – that allows for a deeper understanding of challenges that arise with performing a complete VDT approach.

2. Theoretical Background

The following subsections provide an understanding of IS, DS, and IM in the context of the creative innovation development approach DT. Due to the aim of enabling a VDT approach, subsection 2.1 outlines how IS research is approached in this contribution. This is done by presenting IS as field in the context of this dissertation and introducing the specific perspective regarding VDT. The inherent collaborative and creative nature of DT requires the examination of the status quo on virtual creative teamwork. The subsection on IS and DT closes with a literature review on existent approaches to virtualize DT.

The relation of DS and DT is illustrated in subsection 2.2, where at first a demarcation of the term 'design' and a brief overview of design (science) history is presented. This is followed by revisiting given concepts that address the evolution of DT. To create an in-depth understanding of DT, the rearrangement of theoretical concepts on DT is necessary to reason the underlying principles of DT and to unfold the interconnections with IS research.

Since DT can be mainly located within the area of IM, subsection 2.3 presents a definition of the term 'innovation', reflects upon IM, and relates IM approaches to DT.

2.1 Information Systems and Design Thinking

The aim of creating a VDT approach reasons the localization of this research in the field of IS. The outline of IS as a research field is necessary due to the major developments that caused its evolution. Globalization, an increasing service society, organizational transformation, and digitalization do not only motivate IS research but also relate to the evolution of DT. Furthermore, the depiction of IS as a research field allows for an examination why and how a VDT approach can be approached. By presenting the four major developments that influence IS research and an IS definition that underlies this dissertation, it is outlined why and how a socio-cognitive view is applied for the VDT approach (subsection 2.1.1). since the performance of DT – analog or virtual – is inherently creative, subsection 2.1.2 presents a theoretical foundation on research about virtual and creative teamwork. This subsection closes with a presentation of existing research on VDT (subsection 2.1.3).

2.1.1 Information Systems in the context of the thesis

IS and application systems make up a major part of the discipline of Business Informatics, which acts at the intersection between Business Administration and Management as well as Informatics/Computer Science (Laudon et al. 2010). Whereas application systems refer to single software components that serve a specific corporate duty or business field, IS are more holistic since they inherit not only single software systems but organizational requirements in a human context (Gabriel 2016). Hence, IS make up a field within Business Informatics that cares for compiling and applying application systems as artifacts, to approach problem situations with adequate IT (Hevner et al. 2004, Kurian 2013, Laudon et al. 2010).

Although an 'artifact' has different meanings in different fields, the general understanding of the term refers to 'anything made by human skills' (Goldkuhl 2013, p. 53). Within IS research, an artifact is specified as an IT artifact that can come in the form of constructs, models, methods, or instantiations (Hevner et al. 2004). The IT artifact needs to be designed. 'Design' is understood as

process of activities as well as the output (IT artifact) (Walls et al. 1992). The reason to design IT artifacts is motivated by corporate problem contexts as well as increasing technological opportunities and challenges.
IS is a comparably young research area that is driven by four major developments, that are (1) globalization, (2) service society, (3) organizational transformation, and (4) digitalization (Laudon et al. 2010):

(1) Globalization can be understood as an umbrella term that approaches the increasing international interdependences referring to different levels of systems (Pawlowski 2013). Globalization influences IS in terms of increasingly distributed corporate processes, which require software applications that support dispersed work processes and teams, who, in turn, need IS to collaboratively fulfil their tasks. In accordance with IS, the corporate tasks can refer to the design of processes, concept development for the integration of existing or realization of new dispersed systems, or support systems for globally dispersed teams and management (Laudon et al. 2010, Pawlowski 2013). The targeted VDT approach refers to a need for a support system for dispersed teams due to globalized settings.
(2) In developed economies, a transformation from primarily agricultural to an industrial-driven economy was advanced by an increasing service sector, which is characterized by knowledge and information industries that overcome a mass-market orientation toward individualized offers (Laudon et al. 2010). Individualized service innovations can be developed with the support of IT. But beforehand, possible user-centered innovations need to be identified with suitable approaches, such as DT. Through its diverse team settings, a user-focus, and the iterative approach, DT is one example of suitable innovation development approaches that is in line with the changing environment of a service society (Hehn et al. 2018).
(3) Organizational structures and management are subject to constant change, for example from mass production to individualization and automatization as well as working styles, which necessitates correspondent systems. On the one hand, organizational processes of IS development are a subject of matter, and on the other hand, resulting effects of IS application in organizations influence organizational transformation (Orlikowski and Robey 1991). The mutual influence of IS and organizational transformation is also relevant for performing a VDT approach. First, DT inherits a specific collaboration mode and mindset in terms of diverse team settings, no hierarchies, creative, and visual working, which can be different to the way a company and its employees work (Carlgren, Elmqvist, et al. 2016, Schmiedgen et al. 2016). Second, when performing DT virtually the collaboration mode is performed with the use of ICT, which can as well be new to organizations and employees since it changes the way tasks and communication is performed (Furmanek and Daurer 2019).
(4) Digitalization is a term that needs to be demarcated from digitization and digital transformation. Digitization describes the process of transferring information from an analog into a digital sphere (Hess 2019). Further, digitalization, in its first meaning, refers to the transition from originally human-conducted tasks that are transferred to be performed by application systems, hence referring to automatization. The perspective to digitalize specific, recurring corporate tasks was enhanced by an increasing consideration of unstructured processes and overarching tasks that are now digitalized based on advanced technologies and approaches such as big data, data mining, or artificial

intelligence (Hess 2019). Digitalization and digitization together can be specified as elements of the digital transformation, which influence all societal and corporate areas, whereas digital transformation of companies is concerned with new business models, customer-orientations, as well as product, service, and process innovation (Hess 2019, Lattemann and Robra-Bissantz 2005, Robra-Bissantz and Siemon 2019) that can be approached with DT.

The outline of the four major developments that influenced IS research, support an understanding of IS in the context of this work. Following, IS is specified from a technological, organizational, and human point of view. Gabriel (2016) defines IS in its broader sense as technology that is hard- and software combined with humans that together unify in information and communication systems to perform corporate tasks. The focus on communication implies the capture, processing, storage, and transfer of information that is executed through technology, hence ICT. Ultimately, IS consist of humans, machines, and applications that generate or use information and that are connected through communication relationships (Gabriel 2016). Orlikowski and Robey (1991, p. 144) suggest another element in the specification of IS, which includes any hard- and software of one organization that mediate corporate tasks. They further define IT as a '[…] product of human actions as well as the medium for human action'. The holistic understanding of IS that inherits organizations, humans, and machines combined with technology (software, hardware, and applications) for corporate information and communication tasks, is the view that underlies this contribution.

IS research that specifically emphasizes the human can be distinguished in Computer Ethics, Social Informatics, Participatory Design, and Computer-Supported Cooperative Work (CSCW) (Friedman et al. 2008). All four exemplary specifications vary in their characterization and approaches. Whereas the latter area, CSCW, is strongly related to Human Computer Interaction (HCI), a research area that originally emerged when the use of technological devices were new for business purposes outside the natural sciences and informatics. HCI explores how humans and computers interact with each other, being influenced by technological, social, and psychological concerns (Friedman et al. 2008). Research on HCI mirrors an early attempt to holistically examine human values while interacting with technological devices (Friedman et al. 2008). In HCI research methods and models from Psychology are applied, because the technological aspects are new but the insights on human cognition stay the same (Hjørland 2002, Whitworth et al. 2000). HCI refers to individuals interacting with systems or electronic devices. Whereas HCI mainly focuses on the examination of individuals, CSCW deals with how ICT supports or enhances cooperation and collaboration in teams (Laudon et al. 2010). The examination of different types of interaction are at the center of CSCW that can be classified by type of communication, coordination, and cooperation in regard to the requirements a system needs to offer for a (corporate) task (Laudon et al. 2010, Robra-Bissantz and Siemon 2019). Computer-Mediated-Communication (CMC) is part of CSCW, when referred to team collaboration (Whitworth et al. 2000). CMC represents the interconnection of humans via technology (tools and systems), which can be classified as a social act that challenges cognition (Hjørland 2002).

Psychological aspects, such as cognition, can be of different nature and intend. An established approach for understanding the user and the use of ICT is to apply psychologically-driven insights (Hjørland 2002, Tan and Hunter 2002). Hjørland (2002) examines different areas of Psychology and outlines the differences of, amongst others, behaviorism and cognitivism regarding their relevance for IS. To identify appropriate theories, constructs, and effects that serve the underlying research ambitions, the distinction between different areas of Psychology (e.g.

cognition and behaviorism) are relevant for IS research. This research excludes behavior-driven aspects and, hence, the Social Cognitive Theory (SCT) in this context, as it presents self-efficacy in regard to behavior-change on an individual level (Bandura 1986). SCT is a theoretical framework where behavior, cognition, and the environment are described as influential factors when performing tasks, and presents an understanding how to predict individual behavior as well as how to change it (Shu et al. 2011), which relates to learning models that are not part of this research.

This research focuses on cognitivism, which is an individual's construct that can deliver meaningful information on mental models, mechanisms, and processing relevant to ICT and information retrieval. Referring to the process of cognition outside Psychology, can be referred to and specified as applying a 'socio-cognitive view' that deals with a holistic examination of individual cognition as interplay of the brain, mind, and the environment, which is influenced by social and cultural factors in a relationship with the artifact in regard to HCI (Hjørland 2002).

When referring to CSCW and CMC, individual and human information processing that is carried out in a common, collaborative setting is of research interest. Reacting and supporting human information processing – cognition – appropriately represents one of many user needs IS should respond to (Spence and Tsai 1997). Spence and Tsai (1997) refer to human cognition as a mental activity describing many different processes, such as acquisition and internalization of knowledge, comprehension of thoughts, external stimuli, and experiences, as well as the constitution of reasoning, decision-making, and problem-solving (Spence and Tsai 1997). All of these aspects respond to performing DT (subsection 2.2), which is ultimately an important aspect when it comes to performing DT virtually. Cognition-related challenges in IS research can be reflected in the light of media theories, such as the Media Naturalness Theory (MNT), Media Richness Theory (MRT), and the Media Synchronicity Theory (MST) (Daft and Lengel 1986, Dennis et al. 2008, Kock 2004). The media theories explain how human, cognitive, and evolutionary aspects in contrast to system affordances influence virtual performance. Furthermore, a variety of psychological constructs, such as SMM, or effects, such as the McGurk Effect, are commonly applied to explain effects and influences of CMC and ICT usage, and thereby follow a socio-cognitive view in IS research (MacDonald 2018, de Vreede et al. 2012). Subsequently, this research applies the socio-cognitive view as outlined by Hjørland (2002).

2.1.2 Virtual Creative Teamwork

The analog DT approach is based on creativity and teamwork, which implies that a VDT approach should incorporate existing research and insights on virtual creative teamwork in general. Following, a brief presentation on the understanding of teamwork in its analog and virtual version is presented as well as current findings on virtual creative teamwork.

Teamwork inherits specific characteristics, such as an independent and at the same time collaborative working mode of team members that needs to be coordinated and harmonized (Salas et al. 2000). Next, a team's environment is usually changing due to task and team settings, which requires team members to reevaluate and adjust tasks and processes, which, in turn, relies on effective communication. Another challenge of teamwork comes with internal and external information influencing the team and the task. An additional aspect shared by all teams is the limited time frame in which to conduct the task, which requires a commonly shared vision.

Originally, teamwork necessitated the physical presence of all team members, but due to the development and advancement of ICT, teamwork can be performed in a dispersed manner on a virtual level (Gilson et al. 2015, Maynard and Gilson 2014). Virtual teams are influenced by two major dimensions, namely geographical dispersion and CMC (Maynard and Gilson 2014, Webster and Wong 2008). Maynard and Gilson (2014, p. 2) describe the current corporate situation accordingly in stating that 'today's teams rely extensively, and sometimes even exclusively, on technology to communicate'. This development might even increase since the quality, competencies, and variety of CSCW, which are dependent on ICT and CMC, will probably rise, and this is indispensably connected to changes in working structures.

Existing research on the impact of CSCW and ICT to support teamwork is limited and inconclusive, as current studies show that the application of ICT in team contexts can either result in positive, negative, or neutral effects on team performance (Maynard and Gilson 2014). However, virtual teamwork is increasingly applied for specific corporate projects, such as certain IM undertakings (Maynard and Gilson 2014).

This mirrors the aim of this dissertation in examining how a specific collaboration setting – DT – can be performed virtually with a strong emphasis on the creativity that is necessary to perform the user-centered innovation approach. In the given context, the importance of creativity can be described from two perspectives: first, creativity is found to be an important aspect for innovation development (Prud'homme van Reine 2017); and second, a need for satisfying, creative working modes for business purposes has gained importance from an individual's perspective (Kimbell 2012, Reckwitz 2012). This means that creativity needs to be integrated for the improvement of corporate innovation purposes (output-perspective) as well as in the way how innovations are collaboratively developed by individuals (process-perspective) – this also holds true for virtual team settings.

In its analog performance, the creative, collaborative approach DT offers both, the output- and the process-perspective for corporate innovations. The aspect of creativity in virtual teams is already scientifically examined to a certain extent. Here, it is important to distinguish between creativity on a cognitive level and creativity on an outcome level. The former refers to creativity as the individual ability of being creative that is psychologically examined and can be referred to as a talent toward specific cognitive capacities in terms of thinking styles, synthesis, and abduction (Florida 2014, Kolko 2010, Roßbach 2009). The latter attaches creativity to an outcome perspective that can either be the result of a single or of a team process, which advances the perspective on creativity toward a process-output-perspective that is not further specified (Amabile 1988, Howkins 2013, Roßbach 2009). Creative teamwork is supported when diverse opinions, viewpoints, and experiences come together in one collaboration setting, which can be supported by dispersed and multidisciplinary team members (Hargadon and Bechky 2006, Martins and Shalley 2011, Milliken et al. 2003, Taggar 2002, Woodman et al. 1993). Hence, the opportunity of virtual collaboration via CSCW, ICT, and CMC can positively contribute to creativity in teams and support collaborative creativity (Mathieu et al. 2008, Maynard and Gilson 2014, Siemon 2019). In contrast, vam Knippenberg and Schippers (2007) found that in virtual team settings committed for only a short period of time, creativity in teams can be negatively affected (Martins and Shalley 2011). Mediating factors are, for example, the cultural diversity in a team or the number of members, as both factors can negatively influence collaboration due to challenging and complex communication (Martins and Shalley 2011, Zhang et al. 2007). However, the effects that arise while performing creative teamwork virtually is still subject of research due to the explorative and divergent nature of creative work, which is comparably new in corporate settings (Gumienny et al. 2011). Since past research on creative virtual teamwork is inconclusive and given findings highlight controversial outcomes on the effects, further investigations are necessary.

2.1.3 State of the Art of Virtual Design Thinking

To complete the theoretical background on IS and DT, this section briefly outlines the state of the art approaches that generally refer to VDT. Nonetheless, all approaches toward VDT, which mainly locate in the area of DS, Architecture, and Management Education are excluded for the benefit of adhering to the focus of this dissertation as well as to outline the research based on contributions that directly deal with VDT for the performance of corporate innovation.

One of the first researcher teams contributing to VDT research are Hartmann et al. (2010), who concentrate on the specific affordances of prototyping within creative approaches, such as DT, and introduce hardware to support virtual prototyping. The research team around Gumienny et al. (2011, 2013), Gericke et al. (2014), and Wenzel et al. (2013, 2014, 2016) introduce within their several publications one specific artifact, named Tele-Board, for virtually collaborating in a creative manner (as is done in DT), which is an office based system that combines physical, smart whiteboards with audio-videoconferencing. The authors focus on the technical perspective to support virtual collaboration and the necessity to support reporting in a corporate context. This holds also true for the research of Beyhl et al. (2014), who focus on the aspect of documentation during and after the performance of analog and virtually performed DT workshops to create a sustainable knowledge and information basis for corporate innovation.

The intention to explore the application of new technologies for performing DT virtually is pushed forward by Rive and Karmoker (2016), who examine the use of virtual worlds and Virtual Reality (VR) in the context of VDT. The new-technology-perspective holds also true for the work of Gräßler et al. (2017), where the authors examine the application of VR and additive manufacturing to support a VDT performance from a technical and engineering point of view, with a focus on product development. The recently published work of Petrykowski et al. (2019) examines the performance of VDT with an artifact based on a VR whiteboard, which led to an increased user performance for specific DT methods within the general DT approach.

Due to the aspect of different collaboration and communication requirements within different phases in the overall DT approach, a range of publications arose that deal intentionally with the digitalization of specific DT methods, such as the work of Potthoff et al. (2018) and Siemon et al. (2018), which thereby respond partly to the specific requirements within the DT approach.

All of the aforementioned research unites by applying a perspective of examining (parts of) VDT from a technological and system view, where the improvement of the systems stands at the forefront. However, a performance- and process perspective on VDT, which evaluates the experience of team members first and second, the technological requirements is less represented in these works. However, with the publication of Rao (2018), a tendency toward a socio-cognitive evaluation of VDT can be recognized. The author performed a case study introducing how distributed employees of an IT company applied a Design Science Research (DSR) artifact to perform DT virtually. Rao outlines that, from a technical perspective, the performance of VDT is possible, especially due to the high competencies of the employees regarding I(C)T usage. Nonetheless, the presented case concludes that organizational structures and collaboration modes in general needed improvements to allow for the performance of VDT.

The recent work of Furmanek and Daurer (2019) explores new ways: they develop a framework that reflects upon an appropriate communication for the performance of VDT on the basis of MST. This work initially explores the complex collaboration setting of DT and the requirements that come along a virtual performance from a user- and process perspective. This study

represents a socio-cognitive perspective on VDT but is limited to a theoretical investigation without an actual examination of a VDT performance.
Summarizing, past research on VDT mainly focuses on a technological perspective with an exception of the work from Rao (2018) as well as Furmanek and Daurer (2019). Nonetheless, it is important to outline that, thus far, research missed the examination of the holistic DT approach regarding the process, methods, and mindset perspective as well as the inherent complex collaboration mode.

2.2 Design Science and Design Thinking

Only with beginning of this century, DT was clearly defined as an IM approach (Carlgren et al. 2014, Johansson-Sköldberg et al. 2013, Kimbell 2012). Beforehand, DT had varying meanings and intended different processes and outcomes. The varying concepts and approaches named DT, derive from the use of the term in different theoretical discourses of several disciplines, such as diverse fields of Social Sciences (IM, Architecture, and Art), Philosophy, and Engineering (Kimbell 2011). Consequently, there exist variances of meanings, which cause major distinctions of concepts, ultimately leading to a lack of consensus among scholars. This can be solved by first outlining the different contexts of the term 'design' and reflecting it in a historical light (subsection 2.2.1).
The innovation development approach has its roots in DS and practice, which is at the same time the source of other DT approaches that, thus, need to be demarcated from this research. In this regard, a review on literature (subsection 2.2.2) was conducted that presents the evolution of the IM approach DT to build a ground for deriving the actual status quo. Furthermore, the detailed description of past research that led to the DT approach underlying this work discloses important aspects regarding IS research and IM that are necessary to outline for a deeper understanding of the research gap addressed in this dissertation.

2.2.1 Definition of Design

The verb 'to design' has different meanings based on the context in which it is applied, one example is 'to mark something', which is also related to the term 'sign' that is part of the word itself and associated with visually indicating something. The noun 'design' originated from the term 'desseigne', which is similarly the etymological root of 'dessin'/'pattern' and 'drawing' that are associated with designing in terms of aesthetical, manual creation (Weekley 2013). With the increasing popularity of 'design' as a professional activity in the middle of the 19th century, the aesthetics of physical goods stood at the forefront of what design was associated with (Breuer and Eisele 2018). The arts and crafts movement, originating in Great Britain, acted as a counter pole to the industrialization that came with the perception of ugliness, and conferred professionalism to a diverse set of design activities that combined the requirement of function with aesthetics or, more specifically, with beauty (Clutton-Brock 2008). Hence, a societal need for design occurred as a combination of more beauty, function, and craftsmanship (Pevsner 2005). However, design progress can be found in the era of art nouveau that followed the art and crafts movement and was revolutionized by the Bauhaus era, where the notion of design was radically changed (Bürdek 2015). Technological improvements, that came with the industrial revolution, were considered as an opportunity for a novel creation process; Shape and colors were reduced, abstract, and minimalist. Hereafter, with the establishment of DS as applied arts, its scientific discourse with the specialization of certain areas became apparent, such as Product-, Industrial-, or Communication Design, and a strong focus on the function of products entered the design discourse (Cross 2001, Howkins 2013). Hence, it is not surprising that 'to design' can be used synonymously with 'to shape', 'to form', 'to craft', or 'to construct'. By applying new means of production, design is less associated with single pieces that were elaborately created manually, but more with mass products, which opened the path for design in the mass consuming market by smart-designed objects (Sievers and Schröder 2001).

Notwithstanding, the brief overview of design history shows that connotations of what design is or should be is challenged by linguistics and the fact that design touches, among others, Art and Engineering already in its short time of its emancipation by the mid of the 20th century.

Summarizing, no matter whether 'to design' is used as a verb for a process of creation or 'the design' is used as an expression to describe aesthetical and functional objects, the profession of designers and their way of thinking plays a central role to what we call DT nowadays (Johansson-Sköldberg et al. 2013). Moholy-Nagy (1961) already portrayed in an early work that the act of designing requires an attitude that involves the complex handling of relationships. He argues that these relationships are a set of material, form, function, and space aspects as well as social, psychological, technological, and economic influences that need to be considered by the designer in the process of creation. This holistic idea of designing inherits an interdisciplinary, system, and cognitive perspective, which triggered a generation of design academics to discuss the act, the role, and the duty of designing in its different application areas (Kimbell 2011).

With the attempts for the independence of design as a discipline from the 1960s onwards, a major challenge lies within the demarcation from Architecture, Engineering, Art, and Management that absorb DS in their domain. Nonetheless, the scientific discourse on design is pushed forward by proponents that come from Urban Planning, Politics, Economics, and Philosophy since 'true' design academics were rare to not existent yet. Retrospectively, the interdisciplinary discourse with design focus led to certain developments that substantially coined DS and DT. Following, the next section deals with presenting and bringing together the major concepts leading to DT in order to build a joint view, which allows for an in-depth examination of identified proponents and their research.

2.2.2 An Overview of Design Thinking Concepts

With the beginning of the 21st century, several DS researchers conducted systematic literature reviews in order to identify the major streams and concepts that influenced and helped to understand DT (Johansson-Sköldberg et al. 2013, Kimbell 2011). Figure 3 shows the two most popular concepts that are theoretically derived and act as a foundation to further discuss the roots of DT.

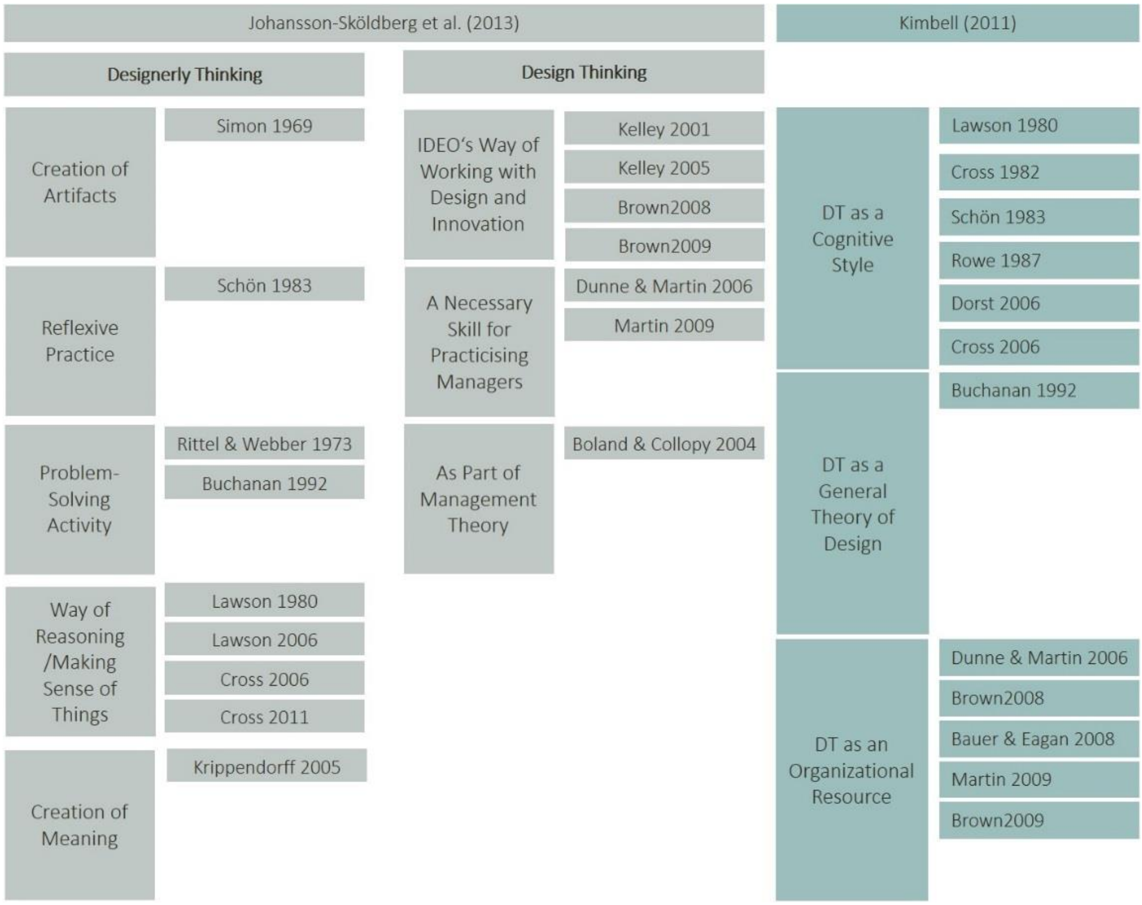

Figure 3 DT concept overview based on Kimbell (2011) and Johansson-Sköldberg et al. (2013)

The presentation of the DT concepts from Kimbell (2011) and Johansson-Sköldberg et al. (2013) show a set of past literature that influenced DT, which was compiled regarding thematic clusters that are further outlined.

Kimbell (2011) identifies three areas of DT: (1) 'DT as Cognitive Style', which is mainly rooted in the 1980s and referring to the examination of the cognitive act of thinking and (re)acting in a designer's way, which can be linked with the DT mindset that is part of the DT approach nowadays. This cluster is reflected in the light of the designer as individual and somehow detached from a designer's environment. Comparably less theoretically represented is (2) 'DT as a General Theory of Design' that deals with the reflection of problem-solving and how design abilities can contribute to that. Another decade later, the development of (3) 'DT as Organizational Resource' began to emerge that deals with design abilities and activities for corporate innovation purposes and Management Education.

Already in (2010), Johansson and Woodilla published a work 'Bridging design and management for sustainability: Epistemological problems and possibilities' where they distinguish two streams in identified, relevant literature, namely 'designerly thinking' and DT. Designerly thinking refers to the academic examination of design practice, whereas DT applies design practice in non-design contexts, especially in Management (Johansson-Sköldberg et al. 2013). Based on this differentiation into two streams, a foundation was built for a further examination of past literature which Johansson-Sköldberg et al. (2013) pursued. Thus, the authors were able to advance their two streams with clusters revolving around designerly thinking: The 'Creation of Artifacts' (Simon 1969), 'Reflexive Practice' (Schön 1983), 'Problem-Solving Activity' (Buchanan 1992, Rittel and Webber 1973), 'Ways of Reasoning /Making Sense of Things' (Cross 1999, 2011, Lawson 1980, 2006), and the 'Creation of Meaning' (Krippendorff 2005).

Furthermore, the DT cluster can be divided into three subthemes based on Johansson-Sköldberg et al. (2013): 'IDEO's way of working with design and innovation' (Kelley and Littman 2001, 2005), 'A necessary skill for practicing managers' (Dunne and Martin 2006, Martin 2009), and 'DT as Part of Management Theory' (Boland and Collopy 2004).

The distinction into a design and a management discourse can as well be found in the work of Hassi and Laasko (2011) 'Conceptions of Design Thinking in the Design and Management Discourse – Open Questions and Possible Directions for Research', who identify less but overlapping authors in each cluster who are already present above.

While comparing the two literature-based concepts of Kimbell (2011) and Johansson-Sköldberg et al. (2013), it becomes apparent that they share most of the sources and expand each other's work in defining streams and clusters that lead to a better understanding of the different meanings of DT and its roots as shown in figure 4. What distinguishes the two overlapping approaches is that the work of Johansson-Sköldberg and her colleagues is referring to single and paired literature works, which are derived and assigned to the cited authors' scientific backgrounds and their epistemology leading to the streams and clusters. In contrast, Kimbell (2011) sorts the reviewed literature in topics relevant to DT. Figure 4 visualizes the fused concepts from Johansson-Sköldberg et al. (2013) and Kimbell (2011) in separating between the designerly thinking and the DT stream; the developed clusters and topics of the authors are set in relation and it becomes apparent that most identified and relevant literature overlap with regards to their assigned affiliation to clusters and topics.

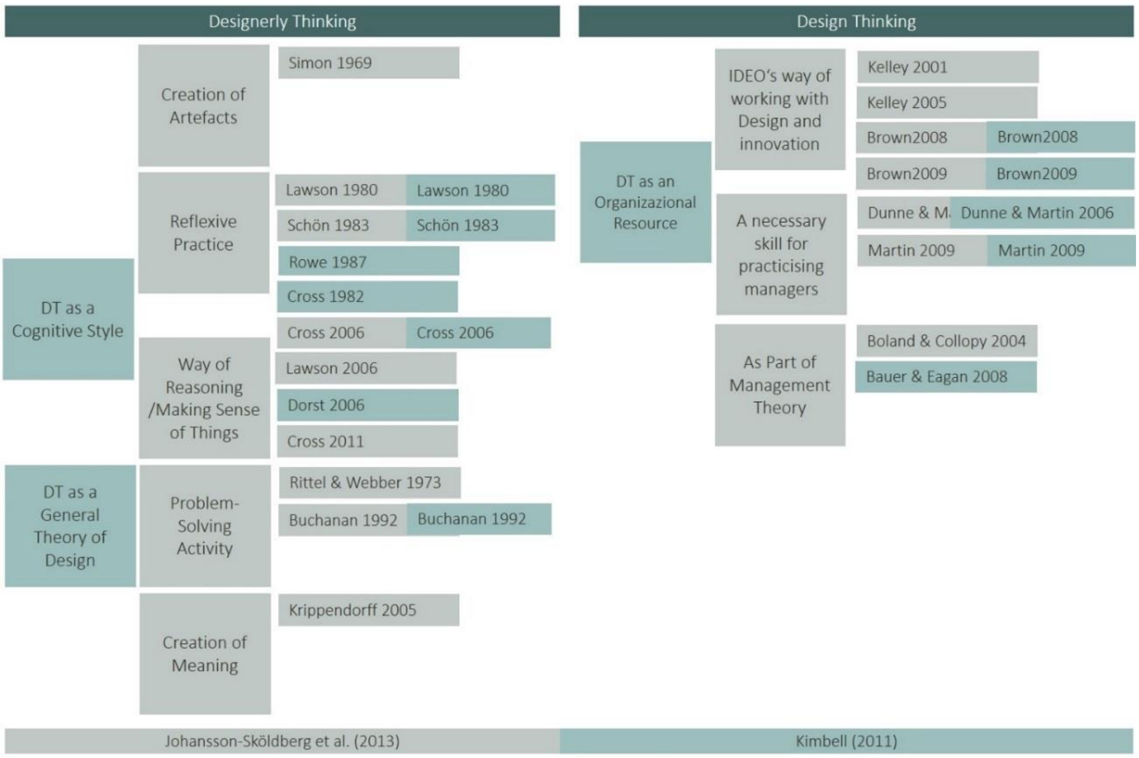

Figure 4 Fused DT concept overview based on Kimbell (2011) and Johansson-Sköldberg et al. (2013)

Furthermore, the reviews from Kimbell (2011) and Johansson-Sköldberg et al. (2013) present a DS-inspired evolution of designerly thinking and DT. Johansson-Sköldberg et al. (2013, p. 125) critically reflect that there can be variants of the concepts due to blurring lines between the examinations of past literature and analyzing the literature in regard to epistemology, which can hinder topic-related, interdisciplinary connections. Thus, an IS- and IM-inspired examination of the evolution of designerly thinking and DT is required in the context of this work, which implies a re-evaluation of the concepts. In this regard, the following subsections portray the evolution of designerly thinking and DT by intertwining IS and IM specific aspects.

2.2.2.1 The Evolution of Designerly Thinking

As outlined in the introduction, DT can be specified as an innovation development approach that applies a problem-solving perspective on the manner designers think and act (Brown 2008, Carlgren et al. 2014). Based on this specification, the following subsections are divided into (1) '*The Artifact*', which responds to the output-perspective of a DT approach, and (2) '*The Wicked Problem*' as a class of problems that can be approached by diverse design-based procedures and acts as the key initiator for starting design action. (3) '*The Designer's Way*' reflects on a designer's process perspective and presents important aspects that later on constitute the DT process, methods, and mindset.

Figure 5 shows the themes of the subsections (1)-(3) that constitute the designerly thinking stream that were re-arranged based on the works from Johansson-Sköldberg et al. (2013) and Kimbell (2011) to create a foundation of discussing the evolution of designerly thinking from an IS and IM perspective.

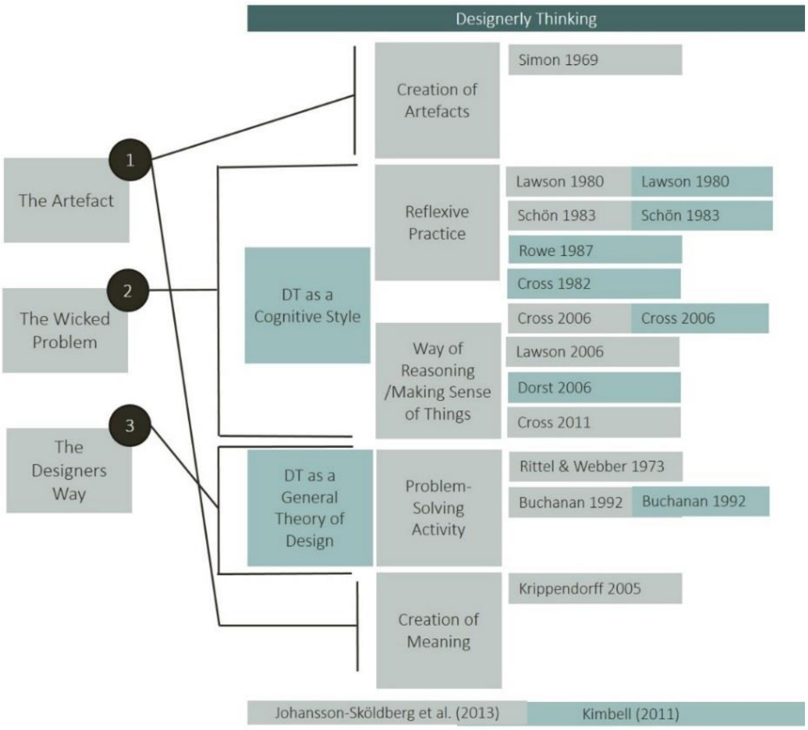

Figure 5 The concept of designerly thinking

The Artifact

Beginning with the end of the 1960s, the economist and political scientist Simon, later on winner of the Nobel prize, published his fundamental essay on 'The Science of the Artificial', where he introduced the term 'artifact'. The term 'artifact' is used in different fields, such as Archaeology, where it refers to anything that is unnatural, or in the field of Medicine where the term is used for the naming of discovered anomalies (Erlhoff et al. 2007). However, Simon (1969) introduced an artifact as a material, unnatural object that is artificially developed by a design process, which means transforming a given setting in one that is better than its original version. Even nowadays, every design item is referred to as an artifact whether in DS or IS. Nonetheless, Simon conceived the process of creation as a necessary step of design activities toward the goal of an artifact creation, which underlines the object rather than a process or value perspective within the design discourse (Johansson-Sköldberg et al. 2013). This goes hand-in-hand with the times of mass production and consumption in the Western world (Bürdek 2015).

Further mirrored in different economic changes, the focus on object- or product orientation changes over the second half of the 20th century with the rise of a service-oriented society. The artifact in the context of DS and practice in its original sense evolves with adaptations in societal, economic, and philosophical progress. The artifact perspective, driven forward by Simon, influenced, amongst others, Design-, Engineering-, and Computer Science, as well as the IS discourse, and led to different discipline-specific characteristics, such as the IT artifact in IS. Next to a change from product to service-orientation, the design artifact became center of an examination on human-centeredness and meaning. In 2005, Krippendorff published his work on 'The Semantic Turn: A New Foundation for Design' where he criticizes the lack of proper emancipation of DS. Based on his academic and practical experience, he outlines how design contributes to the development of 'meaningful artifacts'. In his contribution, he reworks the perspective on the artifact as introduced by Simon and presents a contemporary position of design practice. Hence, the artifact is no longer a synonym for the artificially designed object, but an expression for a created meaning through design activities (Krippendorff 2005). Furthermore, the 'meaningful artifact' is no longer floating in mass production, but embedded in a human-centered reasoning. The design process, therefore, represents a reasonable process, which allows for the development of improved settings that are detached from an object. While Simon already identified the necessity of an interaction between the object-artifact with the user, Krippendorff pushes forward the idea of the human as the driver of value creation for design processes and artifact development (Henderson 2006, Johansson-Sköldberg et al. 2013), which is also connected to the IS research stream of service-dominant-logic that emphasizes value creation for innovation purposes (Vargo and Lusch 2017). With the establishment of the artifact as a 'transmitter of meaning', it becomes a fluid entity of a system that is reasoned by and creates meaning for humans in any circumstances, which refers to satisfaction of needs instead of artificially designing objects that are commercialized to create needs (Henderson 2006, Krippendorff 2005).

Already before Krippendorff speaks up for design as an activity for meaning-creation, a strong focus on technology-driven design caused an intensified examination on the users in interaction with designed technology that led to the establishment of the scientific movement on HCI, CSCW, and CMC. Only with the accomplishment of Krippendorff's work, the separated disciplines of DS IS, and Computer Science, but especially HCI, were legitimized to follow the holistic approach of meaning instead of unreasonable object creation (Henderson 2006). Amongst others, the work of Simon and Krippendorff effectively shaped the term artifact in the reflection of societal, economic, and political Zeitgeist. At the beginning of the 21st century, the official concept of the artifact is being broadened toward services, systems, software, as well as the creation of visualizations next to product development (Erlhoff et al. 2007).

The Wicked Problem

The examination on the design artifact is one of three major developments, which supported the understanding of DT. The artifact might be perceived as the controversy of a design process outcome, but the second theme, 'The Wicked Problem', deals with the specific motivation of why a design action is actually necessary. Already in 1973, Rittel and Webber presented their work on a certain form of problem definition, which supersedes complex problems and are named 'wicked problems'. The authors introduce the concept of wicked problems as a challenge for 'planners' in general – who are not necessarily scientists and/or engineers – but, more specifically, designers and underline the societal aspect that is essential for the definition of this specific class of complex problems (Buchanan 1992, Rittel and Webber 1973, p. 160). Planners can be policy makers that need to make decisions on how to react in a wicked problem context appropriately. Designers, on the contrary, have the ability to reframe problems in order to identify solution spaces as a basis for decision-making (Kimbell 2011).

The characteristics of wicked problems are manifold and cannot be defined nor singled-out in smaller aspects; in other words, they are ill-defined and there can be no final formulation. Hence, there can be no solution of a wicked problem, but rather endless 're-solutions' that require complete knowledge of possible single solutions. More specifically, there is no status of completion since a full understanding of a wicked problem is not possible and a solution needs to be endlessly reworked due to changing settings, information, and knowledge. The never ending wickedness of the problem can never be answered with either true or false, if anything a good or bad solution approach can be considered as evaluation of an intermediate condition (Rittel and Webber 1973). The significance of the problem excuses no trial and error, but only one single action at a time without rules on how to approach single steps of the process of the re-solution. A learning process to tackle wicked problems is restricted due to its uniqueness and the accumulation of diverse problems in a system of problems that cannot be properly explainable (Rittel and Webber 1973). It follows that established scientific approaches, such as proving concepts or hypotheses, cannot be applied for wicked problems (Rittel and Webber 1973). Summarizing, the nature of a wicked problem is that '[…] the aim is not to find truth, but to improve some characteristics of the world where people live.' (Rittel and Webber 1973, p. 167).

Although the description of a wicked problem evokes hopelessness, not even 20 years later, Buchanan (1992) refers to Rittel and Webber's definition of wicked problems by proposing that the abilities of different types of designers can contribute to problem-solving/re-solution-finding. He introduces four different application areas of design, from their original application focus and how they can contribute to problem-solving processes.

The first area (1) 'symbolic and visual communication' refers to Graphic Design, which was originally associated with print materials and illustrations but transformed to the field of Communication Design dealing with the approach on how to best handle '[…] information, ideas, and arguments' through 'synthesis' (Buchanan 1992, p. 10). The second area refers to the (2) 'material design of commodities and machinery', which developed into Product Design as a field that combines Art, Engineering, Natural Sciences, and Humanities (Buchanan 1992, p. 10). Furthermore, the third area (3) 'activities and organized services' that was originally attached to management issues in different areas, such as logistics, resources, and production planning, also integrates Strategic Management issues, which deal with the improvements of experiences (Buchanan 1992, p. 9–10). The final area, (4) '[…] complex systems or environments for living, working, playing, and learning […]' (Buchanan 1992, p. 10), is another area of design that

commonly deals with '[…] systems engineering, architecture, and urban planning […]' – this area broadened toward a holistic understanding of matters, for example sustainable ecosystems subject to cultural change.
These four distinctive design areas not only present a development of different design-based activities, but, more importantly in this context, organize and delimit different fields, such as Management, Architecture, Urban Planning, and Engineering to the context of the design activity and what it is applied for. By identifying the different design-based areas, tasks, and perspectives, Buchanan concludes that 'signs', 'things', 'action', and 'thoughts' are spaces – 'placements' – that can all be handled with different design activities (Buchanan 1992, p. 17). Furthermore, the explanation of the design-based areas with the attached as well as contradicting scientific fields allow for an understanding how differently diverse facets of problems are being faced, which ultimately leads to different communication styles that might not always be compatible. On the one hand, this mirrors the challenge of complete knowledge for wicked problems due to different approaches and communication styles. But, on the other hand, this also identifies opportunities of a possible procedure on how to approach 're-solution' of wicked problems. By introducing design-based areas that touch different disciplines, mutidisciplinarity – with its challenge of different approaches, styles, and languages, as well as its opportunity of combining the best of everything – is the answer for addressing the multitude of complex and simple problems that are combined in wicked problems. With his work, Buchanan paves the way for the applied systems' thought that was already introduced by Rittel and Webber (1973), because he advances a process-perspective on DT, strengthening Rittel and Webber's suggestion for 'an alternative to the linear, step-by-step model of the design process being explored by many designers and design theorists.' (Buchanan 1992, p. 17).
With his interpretation and transfer of knowledge in design-based areas as well as wicked problems, Buchanan (1992) convinces the scientific community that the ability of diverse design-based application areas lead to a multidisciplinary problem-solving approach with the intention of innovation development (Johansson-Sköldberg et al. 2013, Kimbell 2011).

The Designer's Way

Besides the artifact and the wicked problem, a third major development from the past that shaped the future of DT is 'The Designer's Way'. This theme identified from past literature, acts as the roof of several influencing works from Lawson (1980, 2006), Cross (1982, 1999, 2001, 2011), Schön (1983), Rowe (1987), and Dorst (2006, 2011).
Whereas 'The Artifact' refers to an object or rather an outcome of a design action and 'The Wicked Problem' is the key initiating factor for starting and justifying a design action, 'The Designer's Way' deals with the act of designing itself. As already identified by Kimbell (2011) and Johansson-Sköldberg et al. (2013), the above-mentioned authors can be assorted to design-associated cognitive styles, reflective practices, and the designer's way of reasoning as well as making sense in general.
Cross (1982) is one of the proponents who pushed forward the emancipation of design as an own scientific discipline, but he even went one step further in stating that design is next to the Natural Sciences and Humanities an own culture. In his essay from the beginning of the 1980s, he introduces the major values of each culture, which is namely 'truth finding' for Natural Sciences, 'justice' for the Humanities, and 'appropriateness' for DS (Cross 1982, p. 3); the latter is achieved by a combination of the common values of '[…] practicability, ingenuity, empathy […]'. It is also

Cross who first introduces the term 'designerly' as an expression of an own manner in contrast to 'artistic' or 'scientific'. He argues that design equals a technique that combines skills from Natural Science and Humanities for an overarching application area. Cross's further descriptions mostly stem from the findings of Lawson, who conducted behavioral experiments to find out whether, if, and how architects and designers approach tasks differently. In his studies, the originally-trained architect Lawson (1980) found that there are different ways of problem-solving approaches of at least architects and designers. Whereas the architect tries to find a general pattern to figure out the right solution, the designer synthesizes the given information, and reframes the problem, being problem- instead of solution-focused (Cross 1982, Lawson 1980). This perspective opened the path for the introduction of the abductive way of thinking in the design context – next to the established approaches of induction and deduction – that originally award to the designer's approach and that allows for the invention of things that were not imaginable before (Cross 1982, Douglas and Isherwood 2002, Lawson 1980). The major insight that there is something new and different to the designer's approach of problem-solving, goes hand-in-hand with the newly found abductive thinking that is enhanced with Cross's explanation of designers who satisfice rather than 'only' optimize. Hence, the designer's way allows not only for the improvement of something that is given, but inherits a cognitive process which considers diverse alternatives until a reasonable solution appears.

With the ongoing examination of the designer's way, it does not seem surprising that other academics than the design scientists introduced systemized approaches of how design works, for example phase sequences of 'assimilation', 'general study', 'development', and 'communication' referring to the architect's design process (Lawson 2006). Without going too much into detail regarding different design processes of different professions, such as engineers, architects, or managers, the coalescence is that with an ongoing discourse on DS and designer's cognitive and practical approaches, a trend toward systematizing design activities enters the interdisciplinary discussion already from the 1980s onwards.

Advancing and enhancing the designer's way described by Lawson and Cross, Schön (1983) shaped the theoretical movements of designerly thinking with his theory of 'reflective practice'. Basically, as a counterpart to the positivistic and economically driven perspective of Simon's theory of the artifact in 'The Science of the Artificial', the philosopher and urban planner Schön developed a constructivist perspective on designer's cognitive-motivated actions differing from other professions and releases design from a strictly technical-rational association (Johansson-Sköldberg et al. 2013, Kimbell 2011, Soo Meng 2009). Once more, the affiliation of design to either Engineering or Art arises. Nonetheless, Schön develops three different subjects within his examination on reflective practice. The initial point is 'Knowing in Action', which inherits a practice-based knowledge on how to interact in certain professional settings, based on for example education, and is usually a matter of the subconscious (Farrell 2012, Schön 1983). 'Reflection-in-Action' refers to a conscious perception or discussion of something important or worth to perceive within a process of single or collaborate action, which opens a meta-level to reframe problem situations (Farrell 2012, Soo Meng 2009, Waks 2001). 'Reflection-on-Action' as Schön's third subject and refers to a cognitive process of a planned or a past action that allows for more time to reflect (Schön 1983). By introducing 'Reflection-in-Action', Schön presents a technique that is most natural in the profession of design and enhances the activity of 'framing' and 'reframing' within a problem-focus of design activities.

Following, Schön (1983) constitutes another stream of a cognitive way of reasoning that influenced DT and how it is practiced today. Referring to a process-perspective, it is the

combination of 'Reflection-in Action' with 'reframing' that leads to the notion of iteration, which is most common in design practice and is opposing to rigid manners that might be known from engineering activities (Kimbell 2011).
Rowe, an architect and urban planner himself, published his work titled 'Design Thinking' in 1987 where he presents his findings based on case studies within the field of Architecture. He identified both, a sequential, periodic process within the architect's design activities and the work with intuitive-based presuppositions (Kimbell 2011). Consequently, Rowe can be considered as another supporter of the findings that Lawson, Cross, and Schön already implied: a cognitive, intuitive, and abductive way of reasoning within a process sequence, which belongs to the designerly perspective. Although the book of Rowe is titled 'Design Thinking' and he originally introduced the term, it can be associated with the designerly thinking stream defined by Johansson and Woodilla (2010), since the author does not refer to the management perspective that DT takes on.
While the authors Simon, Lawson, Cross, Schön, and Rowe inherit a notion of uncertainty in terms of discipline affiliation and the emancipation of DS in their works, Dorst represents the new generation of designerly thinking. Dorst, trained as an industrial design engineer and design researcher, introduces a joint perspective of the designer's way that he titles 'design methodology' (Dorst 2006). In his work 'Design Problems and Design Paradoxes', Dorst (2006) reflects on the 'design problem' nearly forty years after Simon's rationalist introduction of the artifact, which inspired diverse works on problem definitions, such as the wicked problem of Rittel and Webber (1973) and Buchanan (1992). Innovatively, Dorst considers the artifact and problem perspective as given in design research and, therefore, is able to proceed in terms of content toward a process-perspective. He argues that the reduction of designers to only solve ill-defined problems does not reflect the designer's cognitive and action-based process and, hence, suggests an alternating process that inherits ill- and well-defined problems. Based on the iterating actions of designers that inherit a framing and reframing that leads to synthesis, the problem structure changes over time. Dorst, furthermore, elaborates on the existence of a 'problem space' and a 'solution space', which need to develop in co-existence (Dorst 2006, p. 10). Ultimately, the problem- or solution-focus introduced by Lawson and Cross in the 1980s is superseded by an explorative perspective. This process of alternating 'spaces' does also explain the effect of 'surprises', referred to by Schön (1983) that can be associated with insights resulting in the interplay of problem- and solution-space through information gathering. Furthermore, Dorst is one of the first to include the multidisciplinary perspective when looking at a stakeholder integration in the designer's process. This is reasoned by the necessity of information gathering, reframing, and diverse perspective integration to enable the designers to redefine and develop a standpoint. Thus, Dorst (2006) succeeds at portraying a holistic, co-creative, and process-oriented approach of the designer's way that reveals important characteristics specifying the designer's way of tackling (wicked) problems to create artifacts, which have – over the course of time – diversified their appearance from products to services and ultimately to value creation (Krippendorff 2005).
Summarizing, from the 1960s onwards, DS remains in its formation phase toward an internally and externally recognized scientific discipline. Therefore, the authors of the above-mentioned theoretical developments come from different disciplines, such as Philosophy or Social Sciences, for example Architecture, Urban Planning, or Economics. The previously discussed three themes – the artifact, the wicked problem, and the designer's way – align to one discourse that analyzes the affordances, requirements, and the application of designer's thinking, knowing, and doing to

justify DS, on the one hand, and to apply the procedure within other contexts, on the other hand. Comparable to a process of diffusion, concepts such as wicked problems do not solely influence DS, but also the original discipline they derive from. As already identified by several researchers, the stream of designerly thinking is still ongoing (Dorst 2011, Oxman 2017), and, as the previous sections have highlighted, provides the foundation for the IM discourse of DT.

2.2.2.2 The Evolution of Design Thinking

Whereas designerly thinking refers to the practice of designers, DT applies design practice in non-design contexts, more specifically in management practice (Johansson-Sköldberg et al. 2013). In this section, an understanding of the evolution of DT is outlined. Referring to Johansson-Sköldberg et al. (2013), Hassi and Laasko (2011), and Kimbell (2011), the uprising of DT can be characterized as a discourse essentially pushed forward by management studies (IM, Management Education, and Strategic Management) taking on a managerial perspective. Figure 6 shows a merged view of the concept from DS researchers, which is referring to 'DT as an Organizational Resource' in general and can be further subdivided in (a) 'IDEO's way of working with design and innovation', (b) 'A necessary skill for practicing managers', and (c) DT 'As part of Management Theory'. While Johansson-Sköldberg et al. (2013) in their literature review date the first publication clearly relating to the management discourse of DT back to 2001, they derive a prequel in the specification and uprising in of 'Design Management' from the 1970s onwards, trying to detach DS and activities from its manifold context. But the attempted positivist takeover of design failed and both streams, designerly thinking and DT, can be located in the area of constructivism.
The topics and clusters were derived from a DS perspective, which can lead to confusion when it comes to an examination from an IS and IM perspective. For example, the cluster DT 'As Part of Management Theory' does not refer to management theory but to an increasing theoretical examination of DT in management research. Ultimately, the topics and clusters were rearranged to allow for an IM and IS perspective on the evolution of DT. The black lines in figure 6 indicate how the former concepts from the DS researcher inform the newly conceptualized themes (1)-(3). With the examination of the evolution, DT sits at the intersection of the scientific and applied field of IM, Management Education, and Strategic Management as a priori, which integrates design activity elements in existing areas for the improvement of business and corporate interests (Kimbell 2011). Therefore, an increasing importance of creative working in the business world, where creativity has less reason for existence than the fulfilment of the right numbers and deadlines, slowly emerged (Florida 2014, Johansson-Sköldberg et al. 2013, Kimbell 2011, Reckwitz 2012).

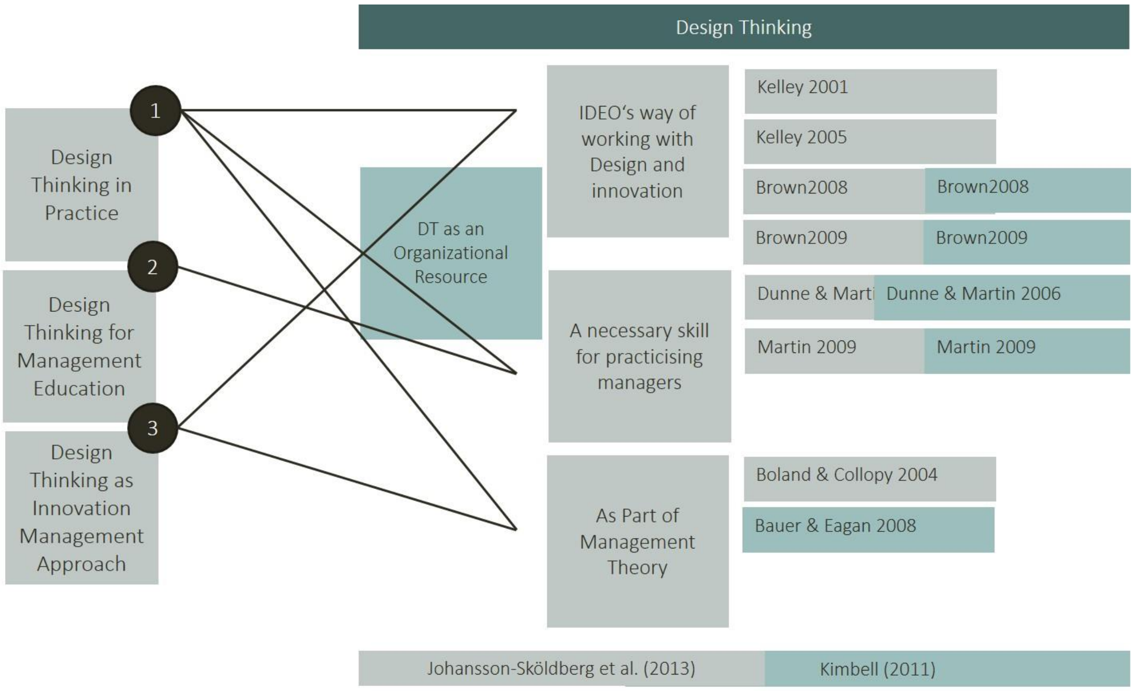

Figure 6 The evolution of DT

Following, the evolution of DT is outlined within three sections that present different aspects on DT from an IS and IM perspective commonly important to understand the status quo of research on DT nowadays (see figure 6). Hence, subsection 'Design Thinking in Practice' presents the practice-inspired beginnings from the innovation development approach DT. This is followed by subsection 'Design Thinking for Management Education' as a specific application area of DT from a managerial perspective. Subsection 'Design Thinking as an Innovation Development Approach' closes the examination of the evolution of DT and leads over to the subsequent section on 'Innovation Management and Design Thinking'.

Design Thinking in Practice

With the publication and increasing public attention of the way designers and non-designers work together on the behalf of the US-American agency IDEO, with its major proponents Tom and David Kelley as well as Brown, a process-oriented DT that can be exercised by diverse professions arose. The design-based collaboration results in fruitful innovation for a range of application areas, such as social, political, and business innovation (Johansson-Sköldberg et al. 2013, Kelley and Littman 2001). The work of IDEO was located by the proponents itself within the area of Strategic Management and introduces a loose idea of how creativity can be used – mostly in the form of using certain methods in teams – to generate innovative output in a fast way and on a globalized market (Bauer and Eagan 2008, Kelley and Littman 2001, Wylant 2008). The earlier works of Kelley and Littman (2001, 2005) refer to applying a designer's approach to innovation development, whereas the later works of Brown (2008, 2009) directly name 'Design Thinking' as the managerial tool for innovation development.

Kelley and Littman's work (2001) on DT presents an unconventional, creative, and collaborative innovation approach that is new in terms of working style, motivation, and application. Without the restriction of building on epistemology, 'The Art of Innovation' stresses on specific aspects that improve the development of innovativeness such as a user-centered focus and empathy, no hierarchies in teamwork, as well as open spaces to support creative working styles (Kelley and

Littman 2001). Brown (2008) refers to DT as being composed of three major elements that are 'desirability' for customer satisfaction by applying the designer's methods, 'technological feasibility', and 'viability' to transfer the value to the market.
The observations from DT interactions led Kelly and Littman (2001, 2005) as well as Brown (2008, 2009) to build an unorganized foundation of what will later on act as a basis for systematizing the creative innovation approach DT. The above-mentioned authors describe multiple cases in their works presenting the initiation and reframing of problems, methods on how the multidisciplinary teams can approach their tasks, and which implications the outcomes have on a meta-level for a management of companies. Moreover, the publications from the IDEO squad are based on experiences and cases that lack in scientific rigor. 'Design Thinking in Practice' can be characterized in terms of a clear application- and output-focus that detaches itself from pure, arty, and individual designer's work. Retrospectively, the outreach of the Kelley's', Littman's, and Brown's works at the beginning of the 21st century led to the facilitation of DT and initiated a kick-start without scientific structure or background.

Design Thinking for Management Education

Working closely together with the IDEO squad, Martin and Dunne (2006, 2009) transferred the idea of DT to the curricula of business schools. Following, DT entered the field of Management Education. Although now touching a specific area within the management discipline, the storyline of emphasizing the importance of DT stays the same as it did in the work of the Kelley's, Littman, and Brown, and refers to a globalized innovation pressure that requires a change in the business world (Brown 2008, Dunne and Martin 2006). The basic idea essential to DT in Management Education is to address managerial problems with designerly problem-solving, which results in opening problem-solving up to embracing constraints, and adding synthesis next to analytical thinking (Dunne and Martin 2006, Martin 2009). Referring to Kelley and Littman (2001) and Brown (2008), Dunne and Martin (2006) derive three major aspects necessary in DT, namely cognition, attitude, and interpersonal levels. Within the cognitive aspect, thinking modes, such as induction, abduction, and deduction, are referred to in an iterative cycle, added by the attitudinal aspect to work project-oriented, to find solutions within a constraint-environment, and to collaborate in a multidisciplinary, interpersonal sphere, ultimately integrating multiple perspectives and empathizing with the user (Dunne and Martin 2006). Additionally, within the setting of DT and Management Education, the focus lies on the importance of appreciating the influences of design, and opening up the path for reflecting on competences necessary for managers (Johansson-Sköldberg et al. 2013). By transferring DT to an object of research in Management Education, the first attempts to systematize DT in management research is set (Rauth et al. 2010). By building on the designerly thinking proponents Schön (1983), Lawson (1980), and Dorst (2006), the approach to also develop a common DT process-perspective is introduced in management studies (Dunne and Martin 2006, Johansson-Sköldberg et al. 2013, Kolko 2010, Martin 2009).
Another aspect that arises within DT in Management Education is a focus on certain and singled-out methods which are applied by designers, such as a stakeholder analysis or blueprints, which refer to the DT methods that are applied in the status quo DT approach (Johansson-Sköldberg et al. 2013). Referring to Brown's and Martin's implication for an increased importance of 'design-methods', Liedtka and Oglivie (2011) introduce specific methods that can be used in DT. The methods apply to the requirements of the process-perspective and can be assembled in a diverse

set in order to respond to certain tasks within the iterative DT process. However, a transfer to research-based examination of DT led to advanced motivation to systematize DT and to further develop the approach for the purpose of IM.

Design Thinking as an Innovation Management Approach

Within the evolution of DT, a struggle on its belongin within management studies, i.e. either in Strategic Management, Management Education and/or Organizational Management, occurs. All fields belong to Business Administration in general, whereas Management Education can be considered as part of Organizational Management. The authors Boland and Collopy (2004) and Bauer and Eagan (2008) take over the name 'Design Thinking' as a rational process that is applied discipline-specific in organization and management, likewise in Engineering or Architecture (Boland and Collopy 2004, Johansson-Sköldberg et al. 2013).

In this regard, DT is further delimited from the notion of an individual designer's task to collaboration in team processes analyzing the origin and application of a DT concept, which inherits thinking modes, use of methods, and process steps (Bauer and Eagan 2008). This perspective is a vital difference to the designerly thinking discourse since the individual designer's performance plays only a minor role in the context of teamwork and team performance. Ultimately, DT is regarded as an appropriate innovation development approach that is primarily conceptualized from a research-based perspective.

Although it is oftentimes criticized that the DT management discourse lacks reflecting designerly thinking – hence the roots of DT, several authors presented DT in the light of its past (Bauer and Eagan 2008, Boland and Collopy 2004). Here, the process-perspective that Dorst (2006) takes from designerly thinking is forwarded to a management perspective, where past findings flow into a conceptual approach, which inherits the artifact, the wicked problem, and the designer's way.

From the 2010s onwards, publications dealing with DT research position themselves in Organizational Management (Management Education, organizational transformation) and/or in Strategic Management (leadership, capabilities) (Carlgren, Elmqvist, et al. 2016, Carlgren et al. 2014, Carlgren, Rauth, et al. 2016, Elsbach and Stigliani 2018, Hassi and Laakso 2011, Rauth et al. 2010). This becomes apparent by examining the publications on DT, which build on the management discourse, as defined by Johansson-Sköldberg et al. (2010, 2013) or at least refer and cite a given set of authors, who refer to the DT management discource, such as Kelley, Brown, and Martin. While comparing the works of, for example, Carlgren et al. (2016, 2014, 2016), Hassi and Laasko (2011), and Elsbach and Stigliniani (2018), it becomes apparent that in order to discuss DT, there is no need to root it in a specific management field. But in the above-mentioned works, DT is either related to Strategic- or Organizational Management, and always refer to innovation and IM as a major goal of DT. This can be exemplary seen in Hassi and Laasko (2011, p. 2) who label DT as a 'method for innovation and creating value' and were one of the first authors to base their research within the DT management discourse in general. In conclusion, innovating and innovations are the core activity and outcome of DT.

The three perspectives of DT in a management discourse – 'Design Thinking in Practice', 'Design Thinking for Management Education', and 'Design Thinking as an Innovation Development Approach' – influenced each other and contributed to the establishment of the state of the art of DT (chapter 3). In the context of this dissertation, DT is addressed as an innovation development approach, which will be reflected in the light of IM in the following subsection 2.3.

2.3 Innovation Management and Design Thinking

Since DT is a creative, collaborative approach to develop innovations, the following subsection 2.3.1 presents the definition of innovation that underlies this contribution. Following, subsection 2.3.2 presents an understanding of IM as a distinct area within Business Administration in order to reason the link between DT and IM. Furthermore, a reflection on IM approaches is outlined for the purpose of framing DT in light of corporate innovation processes.

2.3.1 Definition of Innovation

Since innovating is the major purpose of DT, it is vital to create a common understanding of the term. Generally, the term 'innovation' has a latin origin and stands for something new or novel (novus) and the process of creating something new or to renew something (innovare) (Merriam-Webster 2003, Schuh and Bender 2012). Here, it is important to distinguish between 'new' and 'novel', as the former implies variations of something that already exists while the latter refers to something that did not exist before (Schuh and Bender 2012). 'Something' should at first glance not be further categorized because innovation can refer to any object, product, service, or process and can occur in any field. From a business perspective, Schumpeter introduced the term 'innovation' within the discipline in 1934. He was motivated by macroeconomical examinations and, in doing so, discovered the effect of creative destruction, which refers to a constant notion of change by innovation in several economies and diverse industries (Schumpeter 1934). Creative destruction can lead to destabilizations on the free market due to the introduction of something new or novel (Kurian 2013, McCraw 2007). Object of the creative destruction is the innovation, representing the beginning of a business but also its means for surviving and future success (McCraw 2007, Schumpeter 1934). With Schumpeter as an economist, the foundation for the conception of innovation was set and remains still the same since his definition of the term is broad – including the capture of new target markets as well as product innovation. Thus, the following generations of researchers had to further specify the meaning of innovation in the context of business. Until today, it is still a common approach to use innovation synonymously for idea, products, technology, or processes. Moreover, innovation needs to be distinguished from invention, since an invention is a specified outcome of something radically new, even enhancing the level of novel innovations (Schuh and Bender 2012). The output-perspective on innovation is advanced by an examination of the process of development and the implementation of innovations (Drucker 2002, Schuh and Bender 2012).

Because the focus of this dissertation primarily lies on the process- rather than output-perspective toward innovation, no distinction is being made between the different forms of innovations, i.e. incremental, radical, or disruptive. Hence, the examination of Drucker is most relevant because he already described the need for a systematic practice to enable innovation development in the mid of the 1980s (Drucker 2002). He argues that innovation, as a corporate function, requires 'innovators' who are able to analyze as well as to synthesize (and thereby identify) the potential of user needs and value creation. Deriving from business studies, this perspective could also be applied to designerly thinking, although the proponents do not overlap. Whereas past authors already outlined a process-perspective within designerly thinking as well as within DT, the term innovation in DS is still, astonishingly, highly connected to product innovation, despite implicitly referring to a designer's process (Bürdek 2015).

Nonetheless, with the introduction of innovation by Schumpeter, the importance of innovation processes and outcomes as well as its inherent implementation into corporate activities led to the establishment of IM as a major business concern.

2.3.2 Innovation Management

Innovations are described as specified corporate processes in diverse forms that have commercial potential (Kurian 2013). There are two possible interpretations concerning the location of IM in Business Administration. On the one hand, IM together with Technological Management and Entrepreneurship can be considered as a field of Business Administration (Verband der Hochschullehrer für Betriebswirtschaft e.V. 2019). On the other hand, IM can be characterized as a cross-section within management studies, which is feeding into the established fields of Strategic Management and Organization and Management, amongst others (Drucker 2002, van Oorschot et al. 2018). However, both versions consider IM as interdiciplinary, which underlines the existence of a variety of IM topics and approches in diverse fields from Business Administration.

Moreover, the common ground that combines DT with any field or intention is IM, regardless of whether it refers to Management Education, product, service or value innovation, or leadership or decision-making issues. Locating DT within IM follows the assumption that DT is an approach for the development of innovations, which is supported by any author – whether researching designerly thinking or DT (Brown 2008, Buchanan 1992, Carlgren et al. 2014, Kelley and Littman 2001). Hence, within the context of this contribution, DT is regarded as an innovation approach serving IM, which is supported by Goller and Bessant (2017) and is further outlined in the next section.

2.3.3 Innovation Process Approaches

An innovation process does not refer to the innovation of a process, but is a strategic procedure, organized or modeled for the sake of corporate innovation activities (Tushman and Nadler 1986). Apart from the developments regarding the manifestation of a discipline named 'Innovation Management', the innovation process is a development inherent to managing corporate innovation, increasingly recognized since the popularity of Schumpeter's theory of creative destruction. Examinations on corporate innovation processes in business and science date back to as early as the 1950s (Rothwell 1994). In his work, Rothwell presents five distinctive cycles of differently characterized innovation process approaches:

The first cycle starts around the 1950s and lasts until the mid of the 1960s and is primarily characterized by a 'technology-push' perspective, resulting from an increasing share of research and development departments (R&D). The subsequent cycle lasts until the mid of the 1960s and is mainly characterized by the procedure of following a sequential five-step model – basic science, design and engineering, manufacturing, marketing, and sales. This cycle represents a 'need-pull' motivation to integrate changing user requirements instead of technology-push that oftentimes lingers around constant incremental product innovation and, therefore, misses out on the opportunities for more radical innovations. The third cycle, lasting mainly from the early 1970s to 1985, is shaped by finding an innovation process toward (most) successful innovation for failure-reduction, which stems from an engineers' perspective and promotes a systematic innovation process. The predominant approach of a corporate innovation process can be located between a technology-push and need-pull-orientation. The 'coupled' approach focuses on market needs and innovation capabilities by referring to the possibility of iterations in the otherwise sequential process of (1) market need, (2) development, (3) manufacturing, and (4) sales. This approach is also pushed forward in the fourth cycle, lasting from approximately mid-1980s to the early 1990s, dominated by fast-pacing technological developments combined with a globalized economy, ultimately leading to shortened product-lifecycles and increasing (global) competition. Thereby, the complexity of the business world and, within that, innovation processes increases, which can also be seen in cycle five, starting from the 1990s onwards. Since then, an organization-, time-, cost-, product-, and manufacturing-perspective enters IM with a process made out of six steps – marketing, R&D, product development, production engineering, parts manufacture, and manufacturing. This approach defines single steps that previously have been assigned as one general step, and includes a variety of business departments needing to work together. A strong engineering perspective, on the one hand, leads to a modularization of product properties with the aim for a constant incremental improvement of goods based on the customer's requirements. On the other hand, a more holistic, organizational-driven perspective is pushed forward.

All five cycles as defined by Rothwell (1994) cannot be regarded subsequently since their different specifications fit to different industries that all still exist nowadays and, therefore, any process can still be used in the business world. It follows that the discussion on innovation process developments needs to be reflected in the light of a changing product/manufacturing/ engineering- to a service/knowledge/value-perspective, paired with globalization and digitalization. The changing business environment and different needs of a variety of industries engender different views on innovation processes. Two (opposing) innovation process approaches are the stage-gate-model and the open innovation concept, which both entangle a more holistic, organizational approach than their predecessors.

The well-known stage-gate-model, developed by Cooper in 1990, revolutionized the industry by systematizing innovation development with sequential steps that are assigned to different responsible departments and organized by decision points, thus, creating a rigid procedure to prevent failure (Cooper 1990). This controversially discussed procedure is widely applied in production and manufacturing, the so-called heavy industries, which oftentimes are bound to secrecy rules due to global competition and, therefore, tend to only implement internal innovation processes. It happened also in this light that a specified service innovation development process was developed in 1998 in Germany, where a subsequent and static phase sequence of (1) idea generation and evaluation, (2) requirements, (3) design, (4) implementation, (5) service offering, and (6) dissolution were introduced (DIN - Deutsches Institut für Normung e. V. 1998). This process model, which was oftentimes applied and referred to, represents a stage-gate-inspired-model, where neither the process until idea generation, iteration, nor customer integration finds access.

A realignment of the service development process from 1998 was conducted in 2018/2019 named 'Development of digital service systems', which recommends an iterative phase model of 'analysis', 'implementation', and 'design' that are linked by informal decision-points (DIN - Deutsches Institut für Normung 2018). Each of the phases are informed by a set of methods, which serve user-centricity, customer-integration, and business model development. This advanced innovation process approach reflects on an increased level of corporate service-orientation and digitalized offers for customers, which inherits the idea of open innovation.

The open innovation concept was introduced by Chesbrough at the beginning of the 2000s (Chesbrough 2006). Different to the innovation processes referred to earlier, 'open innovation' is considered as a concept rather than a process. Nonetheless, the concept is the defined continuation of innovation approaches that have already been discussed in the 1980s, for example by Tushman and Nadler (1986) who refers to the ideal business as a business having an unsystematic but successful innovation approach, which inherits the integration of stakeholders inside and outside an organization to learn and be open for disruptive ideas (Tushman and Nadler 1986).

The open innovation concept expects businesses to be (more) innovative, especially with regard to technology, since internal as well as external ideas are considered through the in- and outflow of knowledge streams (Bogers et al. 2018). These knowledge streams can be organized by the help of IS that can be architectures or platforms that are created for the purpose of defining new business models. Consequently, the innovation is targeted in business models that inherit value propositions for customers (Chesbrough 2006). Nonetheless, the creation of knowledge streams requires an absorption of external knowledge to increase corporate innovativeness, which can be achieved through collaboration, co-creation, and the organization of networks (Berthod et al. 2018, Lattemann and Robra-Bissantz 2005). In reflection to that, the open innovation concept, a highly reputable and applied concept nowadays, refers predominantly to branches that inherently act within the service/knowledge/value-perspective, targeting added-values through openness, and are less limited by security reasons. Open innovation can be seen as a roof that enables diverse innovation approaches. One innovation approach inheriting the idea of open innovation is DT.

3. State of the Art Design Thinking

The evolution of designerly thinking and DT presents the route toward the state of the art of DT, which is presented in the following subsections 3.1 through 3.4. The latest examination of DT specifies the approach as essentially based on teamwork (DT teams), being stringently designed, and thereby consisting of a process model (DT process), which inherits specific DT methods to perform the tasks collaboratively that are defined by the single process steps that comes with basic principles in form of a collaboration mode as well as an individual and team mindset (DT mindset) (Brenner et al. 2016, Carlgren, Rauth, et al. 2016).
The overall DT approach can be regarded as a continuation and advancement in the area of IM and especially in the light of open innovation (Carlgren, Rauth, et al. 2016). The solutions of a DT process remain open initially and, therefore, the process is applicable for the innovation of products, services, processes, or business models as an output. The collaboration mode as well as the DT mindset, which comes with the application, need to be arranged in the light of organizational transformation (Dunne 2018, Elsbach and Stigliani 2018). Nonetheless, DT is a holistic approach and is presented in detail in the following sections.

3.1 Design Thinking Process

From 2005 onwards, the DT process was firstly introduced by the Hasso Plattner Institute of Design at Stanford University (d.school) and since then has been adapted by different d.school subsidiaries (i.e. Potsdam and Paris) and various scholars, such as Stickdorn and Schneider (2012), for different purposes (Plattner et al. 2010, Tschimmel 2012). The DT process model can be considered as an advancement of the process-perspective discussed by Rowe (1987) and Schön (1983), amongst others, in systemizing the development process based on designerly thinking (Johansson-Sköldberg et al. 2013). Figure 7 shows an overview of exemplary DT process models from different institutions and authors. For internal consistency, it should be noted that a ‘process model’ is referred to as the accumulation – whether sequencing or iterative – of several process ‘steps’ (equally great as three), which are applied by specific ‘methods’ that should neither be confused with (scientific) ‘methodology’ nor with ‘tools’.

1	Inspiration				Ideation			Implementation		
2	Exploration				Creation		Reflection	Implementation		
3	What is?				What if?		What wows?	What works?		
4	Discover			Define	Develop		Deliver			
5		Understand	Observe	Imperatives	Ideate	Prototype	Test	Storytelling	Pilot	Operation Generation
6		Understand	Observe	Point of View	Ideate	Prototype	Test			
7	Design Challenge	Understand	Observe	Point of View	Ideate	Prototype	Test	Implementation		
8	Empathy			Define	Ideate	Prototype	Test			

1 Brown (2009) I 2 Stickdorn and Schneider (2012) I 3 Liedtka and Ogilvie (2011) I 4 Elsbach and Stigliani (2018) I 5 HPI d.School Paris (2019) I 6 HPI d.School Potsdam (2018) I 7 Redlich, Becker et al. (2018), Redlich, Rechtien et al. (2019) und Siemon (2018) I 8 HPI d.school Stanford (2019)

Figure 7 Overview of exemplary DT process models

Taking a closer look at the different process models presented in figure 7, it becomes apparent that the models vary in their level of detail. While the process of (1) Brown (2009) consists of only three steps, the model introduced and applied by the (5) d.school Paris (2018) consists of nine steps. The design of the process models is influenced, on the one hand, by the application of specific thinking modes, and, on the other hand, by the use of dedicated methods to perform the aimed activities. Moreover, certain process models are recommended for specific settings, such as the process model by (2) Stickdorn and Schneider (2012), who dedicate their work to service innovation, similar to the process model applied by the (7) DETHIS-project dedicated to DT for industrial services (Redlich, Becker, et al. 2018, Redlich, Rechtien, et al. 2019, Siemon et al. 2018). There is no standardized DT process model that is generally applied everywhere. In fact, the DT process models vary in their terminology of the phases, whereas their function, use, and recommended activities in form of methods do resemble or even refer to the same purpose. In regard to this, the process model suggested by (1) Brown (2009), consisting of the phases 'inspiration', 'ideation', and 'implementation', refers in other words to learning about the problem and the people (*understand*), empathizing by *observation* to define a *point of view* and generate *ideas*, and further *prototype* for feedback (*test)*, which describes (written out) the process model of (6) HPI d.school. The comparison of the process models (1) and (6) shows that there are different levels of detail in naming the phases. Here, a plausible conclusion is that the more extensive the phases of a model are subdivided, the easier the tasks per phase can be assigned. To allow for a more fine-grained discussion, this chapter refers to the process model as defined by the (6) HPI d.school Potsdam (2018), consisting of six phases, namely 'understand', 'observe', 'point of view', 'ideate', 'prototype', and 'test'.

Commonly, DT starts with a problem statement that needs to be understood within the DT team. Thus, the understand-phase is important to build team mental models based on an examination of the content and the users, stakeholders, or customers that are attached to the problem for a shared understanding (Badke-Schaub et al. 2010, Dunne and Martin 2006). Analytical and divergent thinking is essential because it allows for an open inspiration and source of content in any form. By reaching a preliminary consensus on what the team is working on, the next phase, observation, can be started. Observing behavior or processes is a procedure that is common in Ethnography and Psychology and carried out with qualitative approaches, such as interviews (Thoring and Müller 2011). This phase aims to build empathy for the user/stakeholder/customer to identify and internalize context-specific challenges and desires directly, in order to provide a basis for reframing the team's personal perspective to the perspective of the potential beneficiaries of the innovation, leading to the point of view-phase.

The point of view-phase is performed via the abductive thinking mode leading to a reframed problem statement that is phrased from the user-perspective, converging the insights gathered in the previous phases. This phase is said to be inherently inspired by DS, thereby creating the foundation for the ideation-phase. The three mentioned phases are the preparation for the ideation-phase, which is characterized by a divergent thinking mode to create as many ideas in response to the redefined problem statement from the point of view-phase. Besides generating multiple, diverse ideas, the target of this phase is to sort, bundle, and cluster the ideas to create categorized solution approaches, as a prerequisite to develop prototypes, which is the task within the following phase, called prototyping. Prototyping is a procedure deriving from Architecture and Engineering where ideas are built physically. Unlike in Architecture and Engineering, in DT the prototyping-phase is a playful, quick approach to create a presentable, physical form of an idea. By finding and building the right form, the idea itself gets particularized and, thereby, refined. The team's task of this specific phase is to create a preliminary output, in any form, to reflect on the idea within the team in preparation of the test-phase. Testing a prototype with stakeholders is central in DT because it ensures user-centricity, but, more importantly, immediately determining whether the targeted innovation might be successful on the market and whether a further development or even implementation is worth considering. Figure 8 gives an overview of the previously described phases with regard to (1) thinking styles, (2) modes of reasoning, and (3) & (4) course of action.

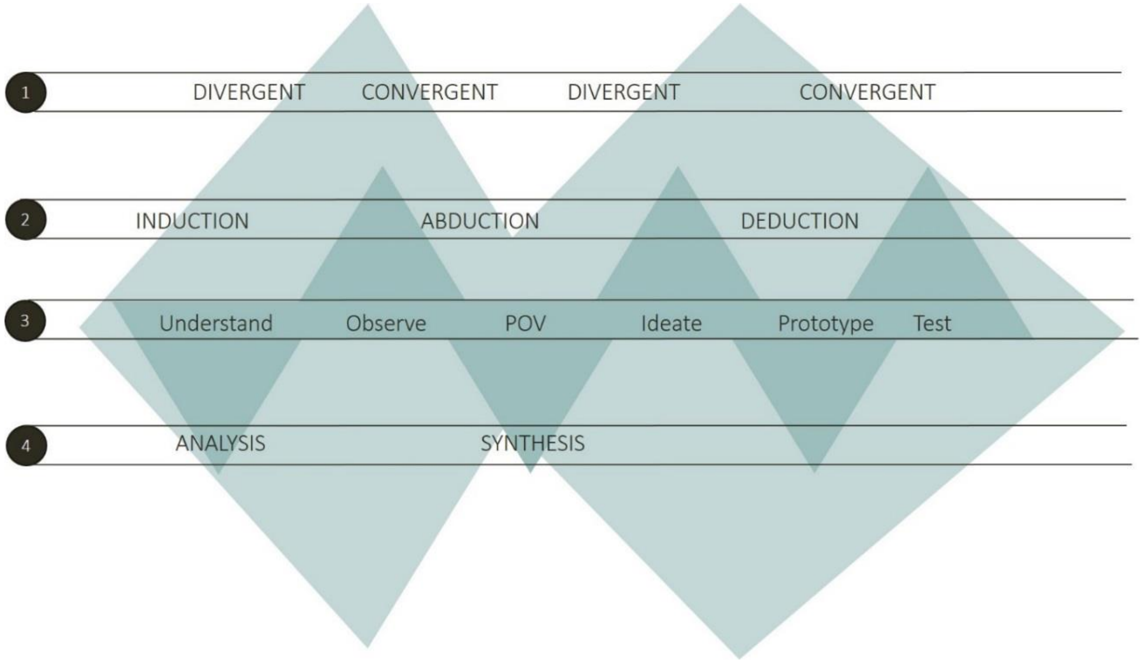

Figure 8 DT phase model with regard to thinking styles, modes of reasoning, and course of action

What has been discussed in DS literature over the last 50 years finds application within the DT process model in the managerial discourse. The process steps stem from different scientific disciplines, such as Ethnography and Engineering, that take different thinking modes as a basis, such as (1) divergent and convergent thinking. In the field of design, convergence is defined as:

> *'[...] when two or more topics, areas, cultures, technologies, or ways of thinking come together. The resulting combinations are dynamic and open, and make way for new combinations, hybrid formations, mixtures, displacements, and innovations to take place. Design enables, restructures, visualizes, and confirms the creation of alternative visual worlds, relevant designs, concrete artifacts, material areas of negotiations, and conceivable references through the dynamics of convergence.'* (Erlhoff et al. 2007, p. 82)

Whereas 'convergent thinking' is referred to as logical steps of thinking, its counterpart 'divergent thinking' refers to creative, associative, and open thinking modes (Siemon and Robra-Bissantz 2014).

Due to the compilation of phases, the 'double-diamond-model' is applied within the DT process model. The double-diamond model derives from DS and describes the alternating thinking modes in creative design interaction, automatically changing from convergent to divergent thinking modes as an answer to the required need to support the design process (Design Council UK 2007, Tschimmel 2012). The specific feature of the double-diamond-model is the specification of two subsequent rounds of first divergent and then convergent thinking, which ultimately forms a double-diamond shape. The double-diamond procedure itself is further specified by the steps of discovering opposing to defining, and developing to delivering, which is also the DT process model as referred to by Elsbach and Stigliani (2018). Nonetheless, the double-diamond-model is appealing in the case of the DT process because it underlines the varying cognitive requirements within collaboration. Additionally, in this regard, the course of framing and reframing, in particular, analyzing and synthesizing, is considered within the DT process model. The difference between an analytical, logical, or positivist approach in contrast to a design-like synthesizing of created insights that are derived based on propositions in a constant iteration leads to another explanation of DT activities. Moreover, analyzing and synthesizing over and over does not only require rethinking but also motivates iteration of a process as a perpetual consequence.

Moreover, the DT process is shaped by all (2) three modes of reasoning: induction, abduction, and deduction (Cross 1982, Douglas and Isherwood 2002, Lawson 1980). While induction is a bottom-up reasoning approach, which starts with observations to derive patterns that are the basis for building propositions reflected with theory, deduction works the other way around. The deductive way of reasoning is a top-down approach starting with theory as a basis to derive hypotheses that are validated by observations to reach confirmation (or not). Abduction, in turn, derives hypotheses from assumptions that are less reliable than the observation from induction. Abductive reasoning inherits experiences and knowledge as preconditions, which hinders a 'validation', such as with deduction, but opens the generation of insights from a less stringent, more intuitive approach. Abduction is part of an important discussion within the design discourse since the abductive way of reasoning can be connected to the designer's thinking and acting, which, ultimately, is the argument why this mode of reasoning is located between induction and deduction, in the center of a DT process model (Kolko 2010, Wylant 2008).

While the double-diamond-model refers to the two 'thinking modes' (convergence and divergence), the change of either a leading positivist or constructivist formal 'attitude' as well as the (re)framing by analysis and synthesis can be regarded as 'cognitive procedures' as statically visualized in figure 9.

Phases	Understand	Observe	Point of View	Ideate	Prototype	Test	
Mode of Reasoning	induction	induction	abduction	deduction	deduction	deduction	Brenner (2016) Wylant (2008)
Cognitive Process	analysis	analysis	synthesis				Brown (2009) Schön (1983)
Positivist or Constructivist Attitude	intuitive	intuitive	analytical	intuitive	analytical	analytical	Martin (2009) Elsbach & Stigliani (2018)
Thinking Mode	divergent	divergent	convergent	divergent	convergent	convergent	Tschimmel (2012)

Figure 9 Thinking- and reasoning styles, cognitive process, and attitudes within the DT process model

However, the assignment of modes of reasoning, thinking modes, cognitive processes, or positivist/constructivist attitude to specific DT phases, as displayed in figure 9, needs to be viewed as preliminary depiction, because the iterative processing in the DT process model leads to the necessity of flexibly changing and re-adapting to different, but required modes (Brown 2009).

The detailed presentation of the DT process model with its varying phase approaches and the application of a variety of thinking- and reasoning modes within the iterative DT process creates an awareness of the complexity that comes with DT. However, without the use of certain DT methods, the DT process model is simply an empty shell.

3.2 Design Thinking Methods

While there is a dedicated DT process, the methods are only designated for the use in DT. Some scholars call them methods, some tools, and others talk about techniques, but all of these terms refer to specified activities that support certain goals as part of a major process (Brenner et al. 2016). Although technically there are no DT methods, the name 'DT methods' is necessary to categorize existing methods as applicable or even essential in certain phases within the DT process. The importance of the use of methods in DT is rated differently – some even refer to DT as a 'toolbox', others value methods as a nice-to-have-but-not-strictly-necessary, and then again, the DT process, methods, and mindset are treated as equally central (Brenner et al. 2016, Kimbell 2009, Liedtka and Ogilvie 2011).
There is no complete set of DT methods, but a variety of sources that provide a selected choice of methods with instructions, examples, and the dedicated phase of application (Doorley et al. 2018, IDEO.ORG 2019). Furthermore, a range of publications exists that presents a specific set of DT methods for certain purposes, such as service- or industrial service innovation (DETHIS 2019, Hehn et al. 2018, Stickdorn and Schneider 2012). There are three dimensions that come with DT methods. First, the classification of methods regarding the phases, modes of reasoning, thinking modes, etc., second, the choice of DT methods with regard to the outcome, and third, the user of the DT methods:

(1) Likewise, the origin or rather the assignment of phases toward disciplines, which furthermore indicate a general idea of reasoning- and thinking mode and a scientific attitude, methods need to align in the context as well. Hence, if a team wants to perform 'understanding', a method that supports induction, analysis, intuitive, and divergent thinking is appropriate, which therefore raises the possibility that a method from Social Science is applicable, for example a stakeholder map (Hehn et al. 2018, Redlich, Becker, et al. 2018, Stickdorn and Schneider 2012). Arguing from the other way around, ‚Brainstorming' is a method that stems from Psychology, which supports divergent thinking, is a useful form of observation within deduction, and is, therefore, ideal in the ideation-phase (Wylant 2008).

(2) Besides the fit of phases and methods to the process-perspective of (1), the choice of methods also needs to be aligned to specific outcomes, such as products, services, or business models. Unlike other innovation development approaches, DT does not start with an idea that directly results in an innovation, but starts with a problem statement that leads to an open-solution attitude at the beginning of a DT process. Further, in every phase that is characterized by identifying needs and generating insights, namely understand, observe, and point of view, there is no inherent outcome-perspective, which makes a, for example, product-orientation redundant and supports an openness toward developing a new value for a need instead of a product that might not be wanted (Redlich, Becker, et al. 2018). Respectively, the form of the outcome can only become apparent after the ideate-phase has been satisfactory. This leads to the necessity of applying methods within the phases of prototyping and testing that support the development of different outcomes' characteristics. Since DT originally derives from a strong product perspective, prototyping methods, such as 'Lego Serious Play' or simply crafting prototypes from given material, are common (Both 2009, Doorley et al. 2018). However, when it comes to service innovation development, other methods are of

advantage to fulfil the requirements of creating something that presents the users the innovation in a way that they are able to give detailed feedback. This can, for example, be through applying appropriate methods, such as 'roleplay', 'customer journey', or 'storytelling', that serve the character of a service (Hehn et al. 2018, Potthoff et al. 2018). Following, the choice of methods for prototyping and testing is challenged by the outcome of the ideate-phase and needs to be selected quite flexibly.

(3) From a designerly thinking perspective, the enormous amount and use of certain methods seems over the top for designers since the guidance that comes with it resembles the intuitive actions that educated designers would do anyway (Cross 1982, Schön 1983). This can be further explained with the application of certain DT methods to allow non-designers to think more like designers (Elsbach and Stigliani 2018). But since DT is more than only designer's thinking for non-designers, the use of certain methods that stem from other disciplines than Design are also new to designers, such as business model generation. Hence, team members methods' expertise in general is challenged due to the interdisciplinary origin of methods and the diversity of the teams. In the end, everybody can apply DT methods but not everybody can guide through them, especially regarding the adherence to (1) and (2).

To summarize, the appropriate application of DT methods requires a thoughtful, but at the same time quick and flexible adaptation to align with the process model. This is further affected by not only applying one method per phase but oftentimes several more, leading to a high number of DT methods that are applied during the innovation development with DT. Figure 10 gives an overview of the choice of methods in a DT workshop concept in the area of service innovation.

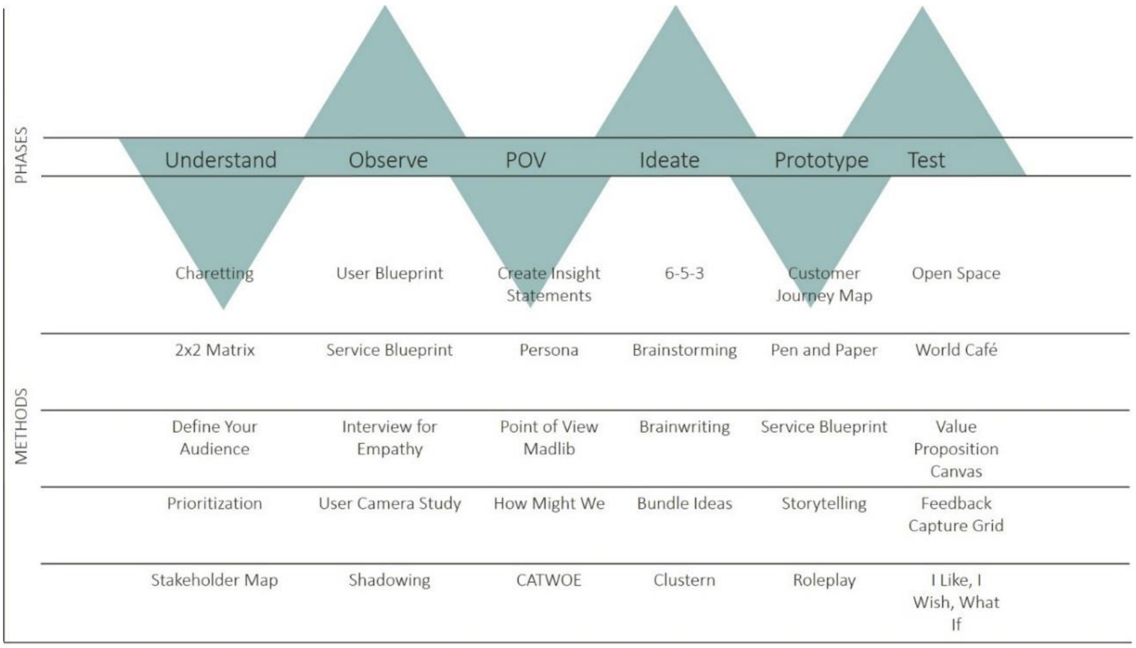

Figure 10 DT workshop concept in the area of service innovation

3.3 Design Thinking Mindset

Next to the DT process model with the DT methods, a mindset specific to DT exists that frames the type of collaboration, hence, the way in which people and teams interact with each other. Other than in the designerly thinking's individual perspective, DT was, from the beginning onwards, a team-focused approach (Cross 2001, Kelley and Littman 2001). Nonetheless, the examination of past research and presenting the discussions on how designers think and work led to the requirement that there is also a specific mindset and working mode in the collaborative nature of the DT approach. Past research on DT oftentimes highlights the importance of the DT mindset regarding the effect during interactions based on the principles of collaboration, but it is also the lasting effect on organizational transformation considered that is triggered by the recurring application of DT (Carlgren, Elmqvist, et al. 2016, Elsbach and Stigliani 2018).

Whereas the development of a process model and methods advanced from the very beginning of the DT discourse and has been systemized, the examination of the DT mindset remained fuzzy for a long time (Dosi et al. 2018, Howard et al. 2015, Johansson-Sköldberg et al. 2013). Challenged by catching the blurry psychologically-driven aspects of the DT concept within the business world, a high amount of different chaotically organized statements of what is necessary to perform DT arose. Through the works of Carlgren, Rauth et al. (2016), Brenner et al. (2016), and Dosi et al. (2018), the idea of what constitutes the DT mindset became more concrete. Carlgren, Rauth et al. (2016) outline the different levels of the DT mindset, namely individual, team, and environment. While the individual level refers to the thinking-, cognitive-, and attitudinal aspects, the team level refers to the competencies when several people are working together; and the environment level refers to requirements, restrictions, and effects in the interplay of the individual and the team. This interplay of the individual and organizational environment is also supported by Hassi and Laasko (2011).

Contrary, Brenner et al. (2016) refer especially to thinking modes, such as convergent and divergent thinking, in their portrayal of the DT mindset which, in the context of this work, is located within the DT process model, because the thinking modes are formally necessary as they derive from the DT concept as such.

Moreover, Dosi et al. (2018) developed a systemized literature review to develop and validate a DT mindset construct for the purpose of measuring the effects that arise. They base their research on a definition of the mindset that inherits the aspects of 'attitudes, opinions, beliefs, and behaviors that characterize an individual, a group, or an organization, mostly developed by experience.' (Dosi et al. 2018, p. 1992). This definition enables the assignment of DT mindset elements in a consistent and organized way, which the authors lay out in a form of a survey, which is the basis for figure 11 that aims to build a coherent understanding of the DT mindset.

	INTANGIBLE	
INDIVIDUAL	A Tolerance for – Being comfortable with Ambiguity – Uncertainty	J Open to different perspectives / diversity
	B Embracing Risk	K Learning oriented
	C Human centeredness	L Experimentation or learn from mistakes or from failure
TEAM	D Empathy / Empathetic	M Experiemntal intelligence / Bias toward action
	E Mindfulness and awareness of the process	N Critical Questioning (,beginner's min', curiosity)
ENVIRONMENT	F Holistic View	O Abductive Thinking
	G Problem Reframing	P Envisioning new things
	H Team Working	Q Creative Confidence
	I Multi-/Inter-/ cross-disciplinary collaborative teams	R Desire to make a difference

Figure 11 Coherent understanding of the DT mindset based on Dosi et al. (2018)

The 19 DT mindset elements from A to R are based on scientific literature and represent a set of attitudes and thinking styles that refer to cognitive efforts on the individual and team level in the

interplay with the environment. Some of the given elements, such as 'G. Problem Reframing' and 'O. Abductive Thinking', refer to thinking styles as outlined in the DT process and DT method section. Thus, these elements need to be understood 'as the ability' to think abductively or to reframe. Another aspect that comes with the presentation of the DT mindset collection of Dosi et al. (2018, p. 1999–2000), is that the lettering of the elements should not be mixed up with a prioritization. Nonetheless, all the mentioned DT mindset elements by Dosi et al. (2018) need to be considered for planning, implementing, executing, and evaluating DT in a corporate context.
The importance of the DT mindset elements lies, among other things, in its difference to the conservative innovation process approaches as outlined by Prud'homme van Reine (2017). He maintains that the major characteristics of past innovation development process models for example, focused on a market-push strategy or an engineering-only-focus, and were overruled by empathetic and user-driven innovation development approaches. Hence, the 'tensions' between old and contemporary approaches reflect a general movement in IM, which is also pushed forward by designers, but not solely through DT. Nonetheless, the DT process, methods, and mindset can be understood as the synthesis of contemporary innovation development approaches.
With the explanation of the DT mindset, the whole DT approach is complete in its current stage. Figure 12 visualizes the three DT elements that constitute the innovation development approach from a theoretical and conceptual point of view.

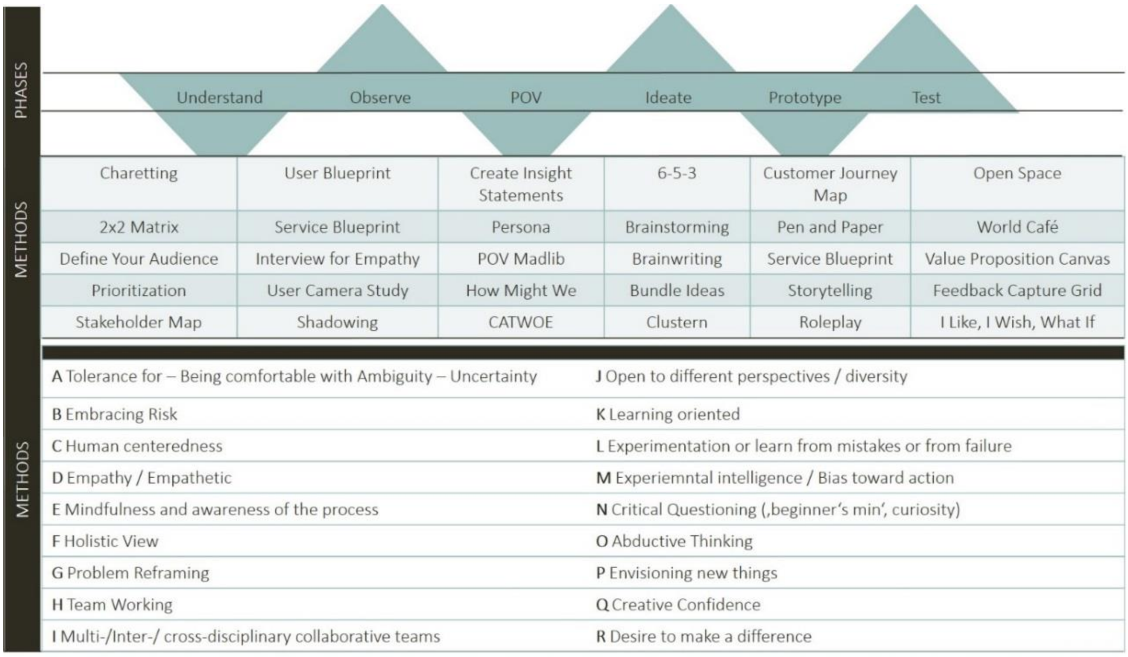

Figure 12 DT elements that constitute the innovation development approach

3.4 Underlying Principles of Design Thinking

In the last few sections, it became apparent how complex the DT approach is conceptualized and what elements it requires in order to be executed successfully. While the triad of the DT process, methods, and mindset forms the intangible DT concept, there are also physical requirements that support the execution of the DT approach. Primarily, these tangible aspects refer to space in terms of room, light, furniture, material, and devices to facilitate flexible and open interaction while the DT approach is practiced (Doorley and Witthoft 2011).

Nonetheless, while the intangible aspects have been outlined in detail, the major sources of the theoretical DT concept can be traced back to four basic principles from which any aspect of the triad can be discussed. The four principles of DT are collaboration, co-creation, creativity, and visualization, and commonly refer to the communication necessary to perform DT (Carlgren, Rauth, et al. 2016, Howard et al. 2015).

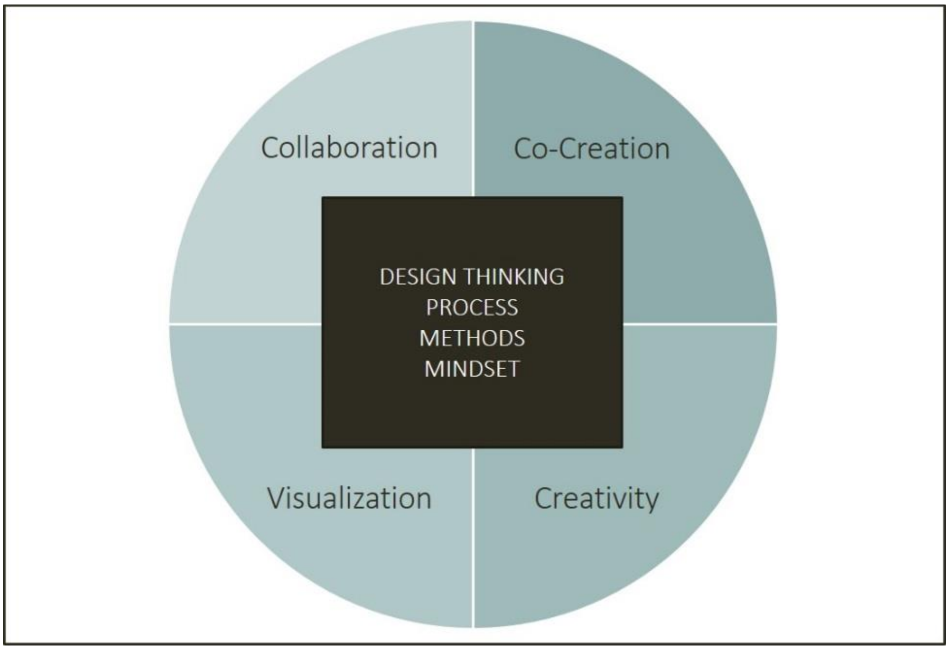

Figure 13 Basic principles of DT in regard to the three major elements

Without any of these aspects, the performance of DT would not be satisfactory. Hence, the four principles are outlined with regard to their necessity to the DT performance. Situated in the context of IM, DT can be further located in the realm of the four principles as application of contemporary innovation development streams.

3.4.1. Collaboration

DT relies on collaboration, which becomes especially apparent through the team-perspective in conducting the DT approach. Collaboration can come in different forms and with different conditions, and is a specified version of cooperation (Robra-Bissantz and Siemon 2019). In general, collaboration can be distinguished between 'coordinated' and 'concerted'. Whereas coordinated collaboration refers to individual deliveries to support a team's work, the concerted version of collaboration means working together for one target without tagging individual works and acting simultaneously (Randrup et al. 2016). The creation process, whether private, non-profit, or corporate, inherits the notion of an effort that leads to a common use of physical and cognitive endeavors to reach a joint goal (Randrup et al. 2016). In this regard, a team can be defined as '[…] people who share a common purpose or goal and interact interpedently within a larger organizational setting' (Lurey and Raisinghani 2001, p. 524). In reflecting with DT, teamwork is based on collaboration in multidisciplinary and diverse member constellations (Dosi et al. 2018). Davis (2010) outlines that the specific kind of collaboration in DT is a most essential principle within the innovation development approach, which further highlights the importance of collaboration as one of four basic principles. Moreover, within the context of this work, collaboration is exercised in a concerted manner in interdependent, diverse, and multidisciplinary teams that spend physical and mental effort toward one or more goals.

3.4.2. Co-Creation

While the collaboration style in a DT team is marked out, the team composition is another issue in DT that needs to be highlighted as a basic principle since collaboration is closely linked to co-creation, which opens the boundaries of teams to commonly generate experiences that integrate user-, stakeholder- and actor needs. Leavy (2012) emphasizes the co-creation-perspective in DT by defining the 'user as collaborator' for a joint value creation.

Co-creation can be regarded as a predecessor of the open innovation development and a specification that deals with value generation from and for users that are part of the development process themselves, hence underlying a customer-company-interaction (Frow et al. 2015, Lattemann and Robra-Bissantz 2005, 2006). The first conceptual movements toward co-creation can be found at the beginning of the 2000s, when Prahalad and Ramaswamy (2000) introduced value co-creation that entails a shift from a mere product- and company-perspective to individualized user-experiences that are generated by collaboration for the purpose of creating economic value (Prahalad and Ramaswamy 2004). From a management perspective, value co-creation has entered an important scientific discussion from the beginning of the 2000s on, namely the service-dominant logic, which outlines a considerable process and change of perspectives how companies and their ecosystems collaboratively co-create value for and with their customers (Berthod et al. 2018, Lusch and Nambisan 2015, Vargo and Lusch 2017). For example through open innovation, customers can support the inflow of external knowledge streams for a company's value co-creation.

The process of co-creation in DT teams refers to either customer integration or users as team informants, which means users as members of the DT team that are external parties that reveal external knowledge. Nonetheless, in both versions, human- and user-centeredness as well as gaining empathy are core motives for co-creation in DT (Carlgren, Rauth, et al. 2016, Dosi et al. 2018, Howard et al. 2015, Liedtka 2011, Schweitzer et al. 2016). Coates and Ind (2013, p. 87) even go one step further within co-creation research, in stating that a value needs to be identified within the development process, but it is the meaning that has to be created, because 'meaning is always co-created'. Consequently, the product-, to service-, to value-perspective is even enhanced by the creation of meaning by co-creative collaboration, which can be linked with Krippendorff's work 'The Semantic Turn: A New Foundation for Design' (2005). This can be regarded as a synchronization within management research and DS with regards to DT, since both streams claim that innovation development is a participatory design process toward a result (artifact) that creates meaning for people, regardless of its form (Carlgren, Rauth, et al. 2016, Coates and Ind 2013, Krippendorff 2005). Past research outlined that DT is an innovation development approach that creates meaning by enabling value co-creation in a collaborative team process (Coates and Ind 2013, Frow et al. 2015, Leavy 2012). Nonetheless, there is a major ingredient missing when putting DT in the light of co-creative collaboration, namely creativity. There is a rising, general agreement within science and business that innovations are more likely to happen (and are more likely to be disruptive) when created in teams rather than by individual people, and that these team processes generally need to be reflected in the light of creativity as an innovation enabler (Coates and Ind 2013, Johnson 2010).

3.4.3. Creativity

To define and isolate creativity as a term or phenomenon, is a major challenge among scholars that has yet to be solved. In the past, creativity was closely connected in the realms of Religion, Art, and Psychology, where mystical, imaginative, and cognitive incidents were described to classify the original and inventive outcomes (Erlhoff et al. 2007, Roßbach 2009). When formalizing creativity, it can be classified as an ability to obtain diverse perspectives fed by preexisting knowledge and imagination that can lead to a perception fostering a possible outcome (Erlhoff et al. 2007). While in the past, a strong connection between creativity to Art and artworks was most common, the term as such was broadened in its application and referred to in scientific disciplines, such as Engineering and Social Science (Erlhoff et al. 2007). Creativity is, therefore, used in different variations of meanings with regard to the applied context and, thus, ultimately calls for a placement. When referring to the psychological classification of the term, a strong association with cognitive processes and thinking styles, such as convergent and divergent thinking, can be identified that are related to the ability of creativity (Roßbach 2009). Hence, creativity can be understood as an individual, mental process of being creative, regardless of the result. Furthermore, creativity happened to be classified and renamed due to its field of use, e.g. artistic-, technological-, and economic creativity that are interrelated with regard to their comparable cognitive approaches (Florida 2014). Similar to a re-distribution of creativity to disciplines, the ability of creativity has also been arranged toward professions. Creative people are often related to specific work groups, such as designers.

Nonetheless, with the emancipation of DS as a discipline, designers themselves oftentimes tried to demarcate themselves from being identified as creative and using the term as an explanation of what they do in order to end a mystification about their profession that is perceived more intuitive than 'real' work (Bürdek 2015, Erlhoff et al. 2007). Contradictory to that, the appreciation of creativity increased within business and management research, which can also be explained with an increasing innovation pressure identified by Schumpeter (1934) and leading to a variety of innovation development approaches that later on appreciated creativity as a necessary ability and means for originality in the business context, regarded as process support toward an outcome with economic value (Erlhoff et al. 2007, Kurian 2013). This can be seen, amongst others, in the work of Verganti (2009) who introduces the importance of design-driven innovation (Kelley and Littman 2001).

Conclusively, creativity needs to be distinguished between the individual ability of being creative (from a psychological perspective) that is specified as an advanced ability in terms of performing thinking styles (divergent and convergent), synthesis, and abduction (Florida 2014, Kolko 2010, Roßbach 2009). Further, creativity can be used to describe an outcome that can either be the result of an individual or team process. Following, creativity can be related to a process-output-perspective that is not further specified (Amabile 1988, Howkins 2013, Roßbach 2009). Moreover, creativity needs to be considered to whether a context deals with individual or team creativity within a process or output focus. The context-specific consideration is especially important when it comes to 'business creativity' with the ambition to infuse creativity in business processes to better solve problems, oftentimes with the help of specific tools (Kurian 2013). Amabile (1988, p. 123) is one of the major proponents who introduced creativity in the sphere of IM and organizational transformation and argues that the 'entire process of individual creativity should be considered as a crucial element in the process of organizational innovation'. Deriving from an idea as the output of a creative process, Amabile (1988, p. 126) furthermore defines '[…] creativity as the production of novel and useful ideas by an individual or small group of individuals working together'. Hence, she opens up the application of creative processes from an individual- and a team perspective with regard to organizational innovation processes (Amabile et al. 1996). It might be considered that the classification of creativity turned from an individual's to a team ability and further to an ingredient, nurturing diverse development processes. In an early examination on creativity, Rhodes (1961) outlines that it is not only an individual that can be creative but also a process, an outcome, and the environment. This holistic view on creativity can also be found in the examination of DT. Sonnenburg (2007) unites the discussion on individual and team creativity by outlining the means of 'cooperative creativity', which describes the individual cognitive affordances of creativity as opposing, for example, the interplay of convergent and divergent, which leads to an interplay of contrasts when it comes to teamwork that fosters creativity.

It is common sense in research on DT that creativity is an innovation booster and indispensibly intertwined within DT (Brown 2008, Carlgren, Rauth, et al. 2016, Johansson-Sköldberg et al. 2013). The relationship between DT and creativity is so close, it happens that both terms are used interchangeably although creativity refers to an ability or attribute and DT is a systematic innovation development approach that applies creativity (Johansson-Sköldberg et al. 2013). Since past research outlined specific cognitive processes, thinking modes, and modes of reasoning that have been identified with the examination of the designer's way (section 2.2.2) (Lawson 1980, Rowe 1987, Schön 1983), these are also part of the creative manner that are applied in DT, which leads, in turn, to creativity being a basic principle.

Furthermore, creativity can also be singled-out within the DT approach by the mentioning of 'creative confidence' in the DT mindset (Dosi et al. 2018). Whereas being creative refers to thinking differently or outside-the-box, it simutaneousley facilitates exploration and it influences other team members, which is in line with the specification on cooperative creativity (Schweitzer et al. 2016, Sonnenburg 2007). Nonetheless, the confidence of being creative refers also to people who are not genuinely creative or trained in 'creative profession', hence it rather refers more to a cognitive mode wether distinct or not, which is accomplished through the systematic DT process model. Furthermore, the exploration in DT fostered by creativity supports embracing risks within development processes that could usually be restricted through only logical and rational approaches (Carlgren, Rauth, et al. 2016).

Summarizing, creativity is a basic principle in DT, which is interrelated and indespensible in the DT process, methods, and mindset for different reasons. In the context of this work, creativity is understood from a process-perspective in terms of integrating thinking styles and reasoning modes as well as cognitive aspects relating to creativity (Amabile 1988, Kimbell 2011, Kolko 2010). Additionaly, this contribution focuses on team- instead of individual creativity, because concerted collaboration, as outlined in section 3.4.1, takes team performance into account where the individual in- and output is seen in the light of the other team members, which decreases the importance of reflecting on individual creativity in DT (Randrup et al. 2016, Sonnenburg 2007). This is additionally supported by Coates and Ind (2013), who outline that co-creation, which can be pursued by DT, should refer to team support to enhance their creativity within the organizational context. Moreover, the just presented three basic principles of DT – collaboration, co-creation, and creativity – are interrelated and hence, facilitated via the application of a certain appoach of communication, which is outlined in the following section.

3.4.4. Visualization

While examining creative work and designers' practise, a constant notion of creating visual images is common. Next to hearing, listening, and speaking, alternative communication modes, such as visualization, play an important role in creative teamwork (Liu and Stasko 2010). As previously established, cognitive processes, thinking styles, and reasoning modes need to be applied to reach the explorative innovativeness requested by the business world. Such cognitive efforts, especially to processes that are alien to one's own profession, can be demanding. This situation is common when teams are compiled to be multidisciplinary, which is common sense in DT. While designers intuitively use this mode of communication, visualization is less common amongst other professions. Nonetheless, the routine of visualization is transferred within DT – as a team instead of an individual approach –, which supports a shared understanding (Bresciani 2019, Liu and Stasko 2010).

Visualization is an activity that inherits an interplay of internal- and external imagery, whereas the internal visualization is a cognitive state of mind that reflects on the environments and oftentimes processes external content (Ware 2012). The internal visualization or images are also refered to as mental models, which play an important role in collaboration, in general and in DT (Badke-Schaub et al. 2010, Swaab et al. 2002). The term 'visualization' can be understood as an image of information or data that is directly combined with cognitive processes of perception that support reasonig (Ware 2012). The visualization works as a support for internal representation and, hence, can reduce complexity that is especially found in wicked problems (Buchanan 1992, Rittel and Webber 1973). An external visualization can come in any form, whether in figures, graphs, or tables, or as sketches or prototypes (Carlgren, Rauth, et al. 2016, Liu et al. 2008).

Thus, visualization can serve as an approach for systemization and shared understanding, when it comes to collaboration in teams (Liu et al. 2008). Whereas research emphasizes the importance of visualization for internal and external communication in DT, the relation between information visualization and creativity is less represented. Johansson-Sköldberg et al. (2013) outline the constant activity of visualization as a mean of sensemaking, which supports the idea of co-creating values (Krippendorff 2005, Randrup et al. 2016). And while the act of visualizing, DT team members create their own facilitator for other modes of communication, supporting the envisioning of new things to physically making them apparent (Dosi et al. 2018, Liedtka 2011). Additionally, it might be considered that visualization supports reframing toward a user-perspective as an external imaginary. Visualization in DT is somehow viewed a generel technique that accompanies the whole collaborative DT approach – the DT process, methods, and mindset – and is, therefore, a basic principle that is indispensible (Carlgren, Rauth, et al. 2016, Howard et al. 2015).

The four basic principles of DT outlined above are derived from the analog, on-site performance of the innovation development approach and act as the guideline on how to design a VDT performance.

4. Research Gap and Research Questions

Within the last chapters 1-3, the introduction and the theoretical background of this dissertation was presented, to establish a basis how the aim of creating a VDT approach is motivated from a scientific point of view. The following lines summarize and structure the insights from the theoretical background to outline the research gap, which informs the underlying research questions of this dissertation.

The initial situation to virtualize DT requires a specification of the commonly analog-performed innovation development approach. As presented in the introduction, this dissertation underlies the understanding of DT the following way:

> *DT is a systematic, multidisciplinary, creative, and user-centered approach for the development of innovations such as products, services, and/or processes that is inherently based on teamwork and it consists of three equivalent elements that are the DT process, methods, and mindset, which jointly constitute the DT approach.*

This specification on DT, based on the works of Kimbell (2011), Johansson-Sköldberg et al. (2013), Brenner et al. (2016), and Carlgren, Rauth et al. (2016), was presented and advanced from two perspectives in chapter 3. First, the three equivalent elements were presented in the light of the evolution of DT and, thereby, outlining the interplay of the DT process, methods, and mindset as well as showing what each of the elements constitute, such as, the necessary application of different thinking styles, reasoning modes, and cognitive processes while performing the DT approach. Second, the detailed examination of the evolution and state of the art of DT, allowed for the outline of the basic principles of analog-performed DT. Collaboration, co-creation, creativity, and visualization are the four principles necessary to make up and perform DT. Each of the principles, jointly found in DT, support contemporary, corporate innovation development (Elsbach and Stigliani 2018, Hassi and Laakso 2011, Robra-Bissantz and Siemon 2019).

The scientific and holistic reflection on DT as well as its application in a multitude of companies, shows that DT is a valuable and appreciated approach for corporate innovation development nowadays (Carlgren, Elmqvist, et al. 2016, DIN - Deutsches Institut für Normung 2018, Schmiedgen et al. 2016, Vargo and Lusch 2017). Though, companies are challenged by the location-dependence of analog-performed DT that requires suitable space (innovation labs) and the presence of multiple employees, customers or stakeholders who form the DT teams (Doorley and Witthoft 2011, Rao 2018). The challenge of location-dependence is reasoned by an increasing dispersed and globalized business world, where employees, customers, and stakeholders are located in different places and need to collaborate on the same task (Laudon et al. 2010, Pawlowski 2013). This is a concern that analog-performed DT is confronted with, since DT teams are diverse and most commonly do not share the same workplace. The challenge of location-dependence can be countered by a VDT approach. The opportunity to digitalize specific, recurring corporate tasks, such as innovation development approaches, is possible through the use of ICT (Hess 2019, Lattemann and Robra-Bissantz 2005, Maynard and Gilson 2014). Past IS research shows that specific, creative teamwork settings can be performed virtually and even enhance the experience of performing a task in contrast to an analog practice (Martins and Shalley 2011, Maynard and Gilson 2014). Amongst others, Furmanek and Daurer (2019), Rao (2018), and Wenzel et al. (2016) outlined that a location-independent, VDT approach is vital to support corporate innovation development. However, past research neglects a holistic examination of a VDT approach by only referring to certain parts of DT or by focusing on possible technological solutions without adhering to the state of the art DT specification. Thus, a VDT approach that considers the inherent teamwork-perspective, the three equivalent elements (DT process, methods, and mindset), as well as the underlying principles of the DT approach, is not yet existent (Furmanek and Daurer 2019). The situation that a VDT approach has been reasoned to be vital for a contemporary, corporate innovation development, combined with a non-existing holistic VDT approach yet, represents the research gap where this dissertation positions itself. Following, the first underlying research question is as follows:

> *How can the DT approach be applied or be improved in a virtual setting with regard to DT process, methods, and mindset as well as the basic principles?*

This research question sets the ground for examining how an effective VDT approach can be established that is satisfactory and applicable in corporate settings while reducing efforts. Here, a first step is to find out, whether a holistic VDT approach is generally likely, a second step needs to investigate how the effectiveness of a VDT can be measured. Due to the process- and performance perspective, a socio-cognitive view is applied when it comes to measuring the success of VDT (Furmanek and Daurer 2019, Rive and Karmoker 2016). The motivation for applying a socio-cognitive view lies in, first, the process- and performance perspective of the targeted VDT approach and, second, in the inherent cognitive affordances within the DT approach itself that need to be sufficiently applicable in a virtual version (Carlgren, Rauth, et al. 2016, Cross 1982, Kimbell 2011, Schön 1983). Hence, the above-mentioned 'effectiveness' refers to the performance of VDT that leads to a satisfying team experience (Santos et al. 2015). In other words, the term 'effectiveness' is used as a depiction for a quality measure that firstly needs to be defined while examining VDT in detail. Thus, this dissertation further aims to find a suitable evaluation approach that enables VDT to be effectively performed, leading to the second underlying research question:

> *How can the effectiveness of virtually performed DT be measured with regard to the adherence of the holistic DT approach from a socio-cognitive perspective?*

To respond to the above presented two research questions, a suitable methodological approach is necessary as presented in the subsequent section.

5. Methodology – Action Design Research

Within the field of IS, a debate on the institutional- and user-centricity of Design Science Research (DSR) occurred during the last decades (Iivari and Venable 2009, Orlikowski and Iacono 2001, Purao et al. 2013, Sein et al. 2011). DSR is a well-known research approach in this field, which is based on the development of IT artifacts from a problem-solving perspective (Hevner et al. 2004). According to that, DSR targets the improvements or responds to a generalized problem without necessarily including a defined context (Iivari and Venable 2009). In contrast, the research methodology Action Research (AR), firstly introduced in the area of Social Science in the 1940s, incorporates the collaboration of researchers and stakeholders to solve an institutional problem detached from a technological perspective. The strong integration of a context in AR and a variety of similarities on how to conduct AR and DSR, acted as a possible inspiration for combining both (Järvinen 2007, Maccani et al. 2015). However, AR does not incorporate the aspect of evaluating technology-driven artifacts, which is crucial for IS research (Iivari and Venable 2009). Whereas DSR neglects the institutional and the stakeholder perspective, AR neglects the IT artifact development (Alter 2015). Based on the argumentation that both research methodologies, AR and DSR, have similarities and can contribute to each other in a combined approach, Action Design Research (ADR) was established as research methodology in IS research (Järvinen 2007, Sein et al. 2011). The practice of ADR goes beyond a passive stakeholder-involvement toward active-involvement in a collaboration setting. By practical, recurring, and purposeful interventions between researchers and stakeholder, knowledge arises that might not be revealed in, for example, interviews (Veling et al. 2016). In combining both approaches, the aim of ADR is an ensemble artifact that is developed on the basis of social collaboration, thereby reflecting real-life settings (Maccani et al. 2015). The term 'ensemble artifact' describes the process and, at the same time, the result of ADR (Purao *et al.*, 2013). Following, the output of ADR inherits an IT artifact in a social context and is, thereby, not limited on an IT 'tool view' (Orlikowski and Iacono 2001, Purao et al. 2013).

Following, ADR inherits a context-specific problem formulation that is solved collaboratively and iteratively in a team of researchers and stakeholder, which results in an ensemble artifact that goes beyond the sphere of an IT artifact for the benefit of a context-specific artifact that responds to an institutional problem situation (Purao et al. 2013). Hereby, not just the institution is set into context but also the stakeholder, in terms of employees, customers, and experts, in a research-based development process (Maccani et al. 2015), which leads to a holistic as well as human-centered development and outcome toward a joint desired goal of a changed situation (Goldkuhl 2013). Generally, ADR inherits the *ensemble artifact*, which is successively build by the insights of *interventions* (see subsection 5.1) that are *evaluated by methods*, such as expert interviews or statistics (Petersson and Lundberg 2016, Sein et al. 2011). These three aspects need to be differentiated to prevent confusion between the role of the intervention and the evaluation method.

Even before the term ADR was introduced, a team of Swedish researchers pursued an AR approach for a computer-supported product design process in the automotive sector, which can be referred to as a predecessor of applying the ADR research methodology (Almefelt et al. 2003). Likewise in this dissertation, the Swedish researchers examined an increasingly digitalized innovation development process and reflect upon the effects of socio-cognitive requirements on CMC in multidisciplinary teams. Although, the artifact was not DT, a structured innovation approach was applied that utilizes creative design methods in team- and workshop settings, which resembles the setting of establishing a VDT approach. Based on the evaluation of documents with qualitative data, such as protocols, and qualitative expert interviews, the authors found that the artifact (use of creative methods on-site and virtually) was well appreciated by the team members and that a team's success is closely linked to team composition. Furthermore, the structured process of innovation development was found to improve the quality of collaboration and results. Almefelt et al. (2003) conclude that a systemized and computer-supported collaboration on the basis of design methods in the field of IM should be further examined with action-inspired research. Furthermore, they outline that the building of a shared vision and intention among team members in interventions is of high importance in such collaboration settings, which refers to an extended examination of socio-cognitive evaluations.

Moreover, Petersson and Lundberg (2016) summarize that ADR is a most suitable research methodology for innovation development approaches that uses design methods' development and application, which need to be adapted to corporate needs in order to justify implementation. The researchers applied ADR for a development project with multiple companies and outlined that an interactive and creative development project, utilizing workshop settings as interventions, enhances cooperation with and commitment to the objective. As referred to in their study on the specific case applying ADR, the evaluation of workshops (interventions) was conducted with questionnaires, observations, recordings, and worksheets (Petersson and Lundberg 2016). However, the authors argue that quantitative methods should also be considered to properly measure the success of the artifact. A mixed-methods approach, applying qualitative and quantitative evaluation methods, is suitable in ADR because of its holistic view on problem situations with a variety of influencing factors (Almefelt et al. 2003, Petersson and Lundberg 2016).

For this dissertation, ADR was considered as the most appropriate research methodology since the IS setting of establishing a VDT approach requires a context- and IT-perspective, which is reflected in the development of an ensemble artifact. In this regard, the VDT approach itself becomes the ensemble artifact that needs to be designed and evaluated for the purpose of user-centered innovation. This is in line with Veling et al. (2015, 2016) who examine the use of DT workshops as a form of intervention in ADR. They outline a noticeable shift in DSR toward the integration of user needs and context, which mirror design practices such as DT. Veling et al. (2015, 2016) refer to DT is an appropriate approach toward user-centered innovation, which can also result in IT artifacts, but argue that it is missing the theoretical and research base in order to serve as a standalone research methodology. Summarizing, the use of DT workshops as a form of intervention in ADR is reasonable (Becker et al. 2019, Veling et al. 2015). Following, a coherence between examined practice and applied research methodology is recommended and hereby referring to ADR and DT.

Thus, the ADR procedure of this dissertation includes the collaboration and feedback from project partners from DETHIS and is the overarching research methodology. But it is common to perform several, recurring cycles within ADR, which in the case of this dissertation resulted in single research studies. The single research studies (see chapter 6-10) were conducted via DSR. The DSR artifacts examined in the research studies can be considered as parts of the overarching ensemble artifact outlined in the chapter 11 'General Conclusions'.

The outlined works from Almefelt et al. (2003) and Petersson and Lundberg (2016) show that the application of ADR is suitable for design-oriented innovation development processes that focus on user needs in creative collaboration settings, as it is the case in this dissertation. In the context of this dissertation, DT workshops are the form of intervention within ADR and the VDT approach is the ensemble artifact, which is in line with the argumentation of Veling et al. (2015, 2016). Nonetheless, to conduct ADR, a research-based, systemized procedure is necessary, which allows for comparison with other works. Thus, the following subsection introduces the underlying ADR-framework that guides through the application of the research methodology.

5.1 Underlying ADR-framework

In order to structure the application of ADR methodology, Sein et al. (2011) developed a framework that guides users through stages (S) and principles (P) of the iterative process. Figure 14 illustrates the ADR framework of Sein et al. (2011).

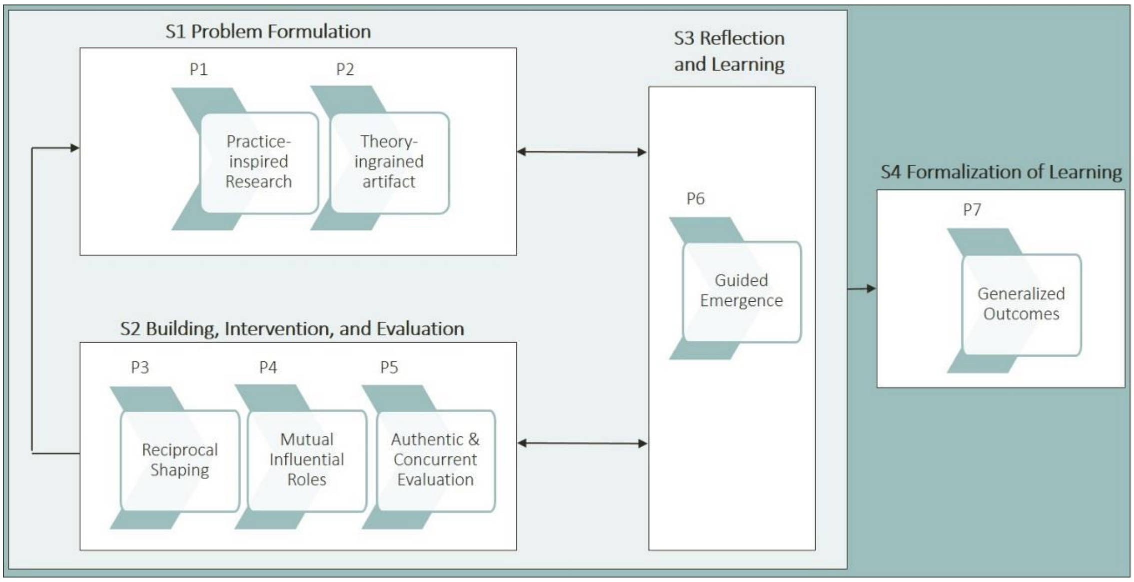

Figure 14 ADR framework based on Sein et al. (2011)

As shown in figure 14, S1 'Problem Formulation' consists, on the one hand, of 'Practice-inspired Research', which includes the identification of a research gap and the formulation of research questions. The underlying problems shall be compiled to a bundle of multitude problem perspectives, respective challenges from practice and / or research-based implications. On the other hand, a 'Theory-ingrained artifact' is conceptualized based on the identification of appropriate technology. The application of ADR requires a lasting commitment of companies and research partners over the targeted duration of the project (Sein et al. 2011).

S2 'Building, Intervention, and Evaluation' (BIE) is a triad, which is iteratively repeated and the specific form of BIE needs to be determined by suiting the setting and S1 in general. Additionally, the research objective should be clear in order to gain the knowledge that is of interest. While performing BIE, different stakeholder groups are necessary that collaborate toward the objective to develop the ensemble artifact (P4 'Mutual Influential Roles'). Single and subsequent BIE cycles can vary based on the gained knowledge that flows into a further execution and the adapted artifact (P3 'Reciprocal Shaping'). The amount of cycles is dependent on the project's progress and cannot be foreseen (P5 'Authentic & Concurrent Evaluation').

S3 'Reflection and Learning' is a constant process within the ADR performance to remind stakeholders and scientists to repeatedly step back and internalize the progress and gained knowledge to yield toward P6 'Guided Emergence'. Tasks that come within S3 include the reflection of design and the change of it, the review whether all principles are applied, and the examination of the intervention results, which need to respond to the project's target (Sein et al. 2011).

S4 'Formalization of Learning' needs to be kept in mind in the overall ADR procedure and also when it comes to S3, but the P7 'Generalized Outcomes' are usually generated at the end of ADR. To generalize the major outcomes, it is necessary to abstract single and general learnings and transfer them to concepts that respond to a class of problems as well as to share the results with stakeholders. Furthermore, design principles should be extracted and the learnings reflected in the light of theory to allow for a formalized dissemination of the results. Following, S4 closes the ADR procedure.

ADR is a young research methodology, which leads to ongoing discussions about it. The ADR-framework of Sein et al. (2011) represents a fine-grained procedure of the research methodology and was accepted and applied within the IS research community since its publication. However, several researchers published adapted frameworks based on Sein et al.'s work (2011). For example, Mullarkey and Hevner (2015) present the given ADR-framework with a more detailed first stage that is divided into 'problem diagnosis' and 'concept design', which allows for the initiation of ADR without an ad hoc development of a first artifact. Another adapted framework is presented by Veling et al. (2016), already including the alternations made by Mullarkey and Hevner (2015) to integrate a further principle into the first stage, named 'build', which dissolves the BIE triad. This is motivated by the fact that the building of the artifact was difficult to conduct within their form of interventions, which resulted in the rearrangement of S1 and S2. Furthermore, the authors added the principle 'embedded observation' within S2 to increase the action-inspired and user-centered perspective within intervention and evaluation. Nonetheless, the altering ADR-frameworks are still very close to the original framework by Sein et al. (2011). The presented adaptations were based on in-depth reflections on already conducted research projects, which allows for a comparison of the given settings to the one proposed in this dissertation. Since the project-specific alternations were not subject of this ADR procedure, this dissertation follows the ADR-framework as presented by Sein et al. (2011), which is further discussed in detail in the following subsection.

5.2 Description of Methodological Procedure based on ADR

According to the framework by Sein et al. (2011), the following subsections are divided into the four stages in ADR, (1) 'Problem Formulation', (2) 'Building, Intervention, and Evaluation', (3) 'Reflection and Learning', and (4) 'Formalization of Learning'. Along the stages, its principles, and the inherent tasks, the specific ADR procedure of this dissertation is presented in detail, yielding toward the aim of a VDT approach.

5.2.1 Problem Formulation

Problem Formulation is the first stage in ADR, which consists of the two principles 'Practice-inspired Research' and 'Theory-ingrained artifact'. The dissertation-specific ADR procedure of this stage and principles are described by outlining a long-term institutional commitment, the underlying problem situation, and research questions as well as contributing theoretical bases and prior technology technological advances. This is followed by an outline of roles, responsibilities, and communication setting underlying the ADR procedure.

Long-Term Institutional Commitment

The ADR procedure of this dissertation was initialized and streamlined with a research opportunity of a long-term and joint project with three companies and four universities, named 'DETHIS – Design Thinking for Industrial Services'. Prior to the official assignment of the project by the German Federal Ministry of Research and Education (BMBF) – including a signed agreement of cooperation between the partners –, a consortium of three companies, four universities, and several associate partners was formed, and the problem situation and general concept for improvement was jointly formulated. The project had two major goals: (1) adapting the DT approach for industrial service providers and (2) virtualizing the DT approach for time- and location independent collaboration. An outline with major facts concerning the research project is presented in figure 15.

Outline of Research Opportunity		
Project name	DETHIS – Design Thinking for Industrial Services	
Project duration	44 months	
Years	2016 to 2019	
Funding	BMBF	
Consortium		**No. of constant working members**
University partners	Jacobs University Bremen	3
	Technical University Braunschweig	3
	Ruhr-University Bochum	3
	University of Duisburg-Essen	2
Corporate partners	Kothes GmbH	2
	RTS Wind AG	2
	Virtimo AG	1

Figure 15 Outline of the research opportunity setting

For each of the two major goals, different teams of multidisciplinary partners were formed according to their expertise, competencies, and motivations. This dissertation is part of the team targeting the virtualization of the DT approach, consisting of Jacobs University Bremen (JUB), Technical University Braunschweig (TUBS), kothes GmbH, and RTS Wind AG. The partner TUBS is represented by the lead and members of the Business Informatics institute that are specialized on collaboration and creativity support systems. JUB, specifically the chair for IS and IM, is the partner that is specialized on research on DT and DT trainings. The two companies are both medium-sized, industrial service provider, who have no dedicated corporate innovation management, distributed subsidiaries, and no prior experience in DT. The companies are faced with an extrinsic innovation pressure and are motivated to apply and implement DT as the major source for innovation development in their company due to their conviction that the user-centered and systemized DT approach supports the companies' future undertakings. Because of their geographic dispersion, there is a need to allow for a virtual performance of DT to make DT indeed applicable for these companies. Constrained resources in terms of travel- and employee costs as well as scarce time allocation are the initial motivation for a VDT approach. Moreover, the companies want to be more innovative in their service offerings and internal structures. It only follows that the companies chose to apply and implement a DT approach, rather than create an innovation department, which would be an established and formalized, but costly procedure toward reaching the goal of being more innovative. The companies want to introduce a corporate innovation process that involves all employees instead of a dedicated unit only.

The Underlying Problem Situation and Research Questions

The underlying problem motivating the research to establish a VDT approach needs to be regarded from different angles, namely (1) the employees' needs, requirements, and competencies, (2) the three equivalent elements and basic principles of the DT approach, and (3) technological opportunities.

(1) The companies' employees have no prior experience with DT and their jobs are mainly not attached to innovation development. The employees' job descriptions of both companies are diverse, ranging from knowledge- to technical workers. None of the employees are designers or hold a degree in comparable areas that are familiar with creative innovation approaches. Furthermore, the IT competences of all employees vary from low to high – i.e. not using computers for work purposes at all to software consulting as a job task. The employees' needs with regard to virtualizing DT need to be considered regarding their IT competencies and their perceived satisfaction and effectiveness as members of DT teams. Furthermore, the VDT approach needs to be applicable next to their original work tasks.

(2) Since DT is an established corporate innovation development approach, its general applicability in the companies is taken for granted. However, to yield toward VDT, the DT process, methods, and mindset as well as the basic principles of DT need to be examined in order to set up a virtual setting that supports or even enhances the development approach in the given context.

(3) The context described in (1)-(2), including challenges, opportunities, and restrictions, need to be reflected in the choice of IT, referring to an appropriate choice of ICT, especially CSCW, to support CMC.

Based on the context and motivation of the research project's goal to establish a VDT approach, the following two research questions were formulated for this dissertation as presented already in chapter 4. The employee-, DT-, and the technology-perspective fuse into a human- and user-centered evaluation and development undertaken from a socio-cognitive perspective.

- *How can the DT approach be applied or be improved in a virtual setting with regard to DT process, methods, and mindset as well as the basic principles?*
- *How can the effectiveness of virtually performed DT be measured with regard to the adherence of the holistic DT approach from a socio-cognitive perspective?*

Contributing Theoretical Bases and Prior Technological Advances

The three major disciplines that are referred to in the context of this dissertation are IS, DS, and IM (see section 2.1 to 2.3). As an underlying theoretical foundation, research on DT in general as well as on virtual creative teamwork, and collaboration was examined and the insights served as a knowledge base for the execution of BIE (see chapter 3). Furthermore, past research on comparable projects to create a VDT approach were constantly monitored (see subsection 2.1.3). The mentioned fields of research were expanded to the search of IS- and psychology-related evaluation approaches to allow for a socio-cognitive view on the enabling of VDT. Aside, a search for different types of ICT, that might support the VDT performance, was conducted to build an appropriate artifact and redevelop it, if necessary.

Roles, Responsibilities, and Communication Setting

The ADR teams were assigned with different roles, which were already fixed with the start of the DETHIS-project. Following, JUB was assigned the role of the DT expert for conceptualization, execution, moderation, and evaluation, as well as general DT research and IM. Both university partners, JUB and TUBS, were dedicated for research on virtual creative teamwork and collaboration, however, each took on a different perspective. The perspective of the TUBS team was to virtualize specific DT- and creativity support methods, whereas the JUB team was dedicated to regard the holistic DT approach. Due to the overlap of motivations and tasks, a vivid exchange of information and insights resulted in a beneficial research collaboration.
The companies' roles resemble a constant collaboration and relevant information transfer. Furthermore, the companies provided actual corporate challenges as initial point for DT workshops, organized the internal DT teams by recruiting colleagues from all levels and departments, and constantly gave feedback on the perceived success, effectiveness, and satisfaction with the (V)DT performance to provide ground for improvement of the VDT approach. The outlined roles mirror the responsibilities in terms of delivering insights, information, and to collaborate in the team. To keep up with a constant progress of the project, JUB was assigned the project management role, which refers to building and maintaining a communication setting and infrastructure. Next to recurring (V)DT workshops (BIE form, interventions), a videoconference with the partners took place every two weeks over the duration of the whole DETHIS-project as well as 2-4 on-site project meetings per year. These collaboration formats allowed for open questions, planned exchange of the project's progress, as well as for the opportunity to step back and internalize the status quo and redefine the concrete tasks in a flexible manner.

5.2.2 Building, Intervention, and Evaluation

Stage 2 in ADR refers to 'Building, Intervention, and Evaluation', which inherits three principles of mutual influential roles, reciprocal shaping as well as authentic and concurrent evaluation. By outlining the initial knowledge-creation target and customized BIE form as well describing the redesign and assessment of the BIE cycles, the specific ADR procedure is outlined in this subsection.

Initial Knowledge-Creation Target and Customized BIE Form

The knowledge-creation target refers to an ensemble artifact, which enables a VDT performance that adheres to basic principles of DT serving the companies requirements, and the stakeholders' needs. Following, the specific form of BIE are recurring DT workshops that are performed in an analog setting at the beginning and are successively performed partly virtually until a complete virtual performance in the end. The procedure of successively virtualizing the DT approach was conducted, on the one hand, to analyze the basic principles (see subsection 3.4) with an action-inspired manner next to the research basis, which resembles the approach of 'verification by application' to allow for a socio-cognitive view (Almefelt et al. 2003). On the other hand, the increasing virtualization allowed for time to acquaint the partners that have no prior experience with DT with the collaboration mode. The DT workshops were mostly conducted with the partner companies but also with students and associate partners in experimental settings to open the perspectives and the knowledge base.

Execute BIE Cycles, Redesign, and Assess

The actual BIE/DT workshops were conceptualized, moderated, and evaluated by DT coaches based on the feedback, research insights, and wishes of the research and practice team, to comply with the principles of mutually influential roles and authentic and concurrent evaluation. Over the course of the project, four major BIE cycles were performed, which, in the case of the third and fourth experiment, included several (V)DT workshops. An overview of the four BIE cycles/experiments is presented in figure 16.

1	Laboratory Experiment
Number of Participants	40
Age range	22-30
gender	34 male; 6 female
Participants Background	Students (Computer Science, Technology-oriented Business Administration, Engineering)
language	English
Number of Teams	10 (5 EG; 5 CG)
Team size	4 members per team
Time frame	20 minutes

2	Exploratory case study
Number of Participants	7 (6 participants and 1 assignment provider)
Age range	23-26 years participants; 45 years assignment provider
gender	All male
Participants Background	Computer Science, Patent Law, Production System Engineering, Business Administration, Mechanical Engineering, Aeronautical Engineering
language	German
Number of Teams	1
Team size	6
Time frame	3 days

3	Practical Experiment
Number of Participants	59 (EG=35; CG=24)
Age range	19 to 22 years
gender	36 male; 23 female
Participants Background	Undergraduate students: Economics, Management, Industrial Engineering, Computer Science, Social Sciences, Intelligent Mobile Systems, Electrical & Computer Engineering, Politics & History, Physics, Biochemistry & Cell Biology, and Medicinal Chemistry & Chemical Biology
Nationalities	27 different nationalities
language	English
Number of Teams	12 (6 EG; 6 CG)
Team size	4-6 team members per team
Time frame	3 days for each CG and EG

4	Five DT Workshops
Number of Participants	24 (analog=16; digital=8)
Age range	From average 32 to average 29 years
gender	17 male; 7 female
Participants Background	Company workshops with participants from different departments and experts from universities taking place as participant.
Nationalities	German
language	German
Number of Teams	5 (3 analog; 2 digital)
Team size	3 to 5.3 team members per team
Time frame	Up to 5 days for each workshop

Figure 16 Overview of BIE cycles and settings

As presented in figure 16, the basic structure of performing parts of or complete (V)DT workshops were the major form of BIE. Besides that, the context, participants, and DT methods changed in the subsequent redesign of the BIE cycles. Following, whereas in cycle 2, an exploratory case study was applied for the building of a DSR artifact, in cycles 1, 3, and 4, experiments in the manner of DSR based on the evaluation of artifacts were conducted. Consequently, it needs to be outlined that the major methodological approach of this dissertation is ADR including the overarching collaboration and feedback from project partners from DETHIS (mutually influential roles), but single BIE cycles were conducted and evaluated via DSR. This procedure resulted in qualitative and quantitative data deriving from, for example, interviews, protocols, surveys, and workshop material (Petersson and Lundberg 2016). Applying DSR for single BIE cycles offers the opportunity to outline the artifact design and redesign for reciprocal shaping. The artifact to enable VDT varies over the course of the project, utilizing different combinations of already established ICT and CSCW.

5.2.3 Reflection and Learning

Through the guided emergence of insights, information, and a step-by-step development of a VDT approach, constant 'Reflection and Learning' (stage 3) is comprised. The VDT approach (ensemble artifact) resembles not only an IT artifact but an instance for virtual creative collaboration with DT, which requires a socio-cognitive view when it comes to human- and user-centered development processes. Next to the increasing research base that accumulated over the course of the ADR performance, the basic principles of DT in its on-site version was manifested in the development team consisting of university partners and companies. However, the corporate setting, outlined earlier in this section, highlighted the diversity of IT competences of staff. This led to an artifact development that supports collaboration for teams whose IT competencies vary from low to high, which narrows the choice of applicable ICT tools down to easy-to-use- and fast-to-learn systems. Following, the artifact development is not characterized by innovative technology usage in terms of hard- and software but acts as a general facilitator for VDT performance by adhering to DT and socio-cognitive effects, relating to perceived success, satisfaction, and effectiveness. This is in line with Veling et al. (2016), who state that the innovativeness of the artifact in terms of technology can play a minor role when it comes to creative virtual collaboration.

5.2.4 Formalization of Learning

Although stage number 4 'Formalization of Learning' originally closes the execution of ADR, this dissertation includes intermediary steps to generalize the outcomes. By abstracting the learnings into concepts for a class of problems and the execution and evaluation of single BIE cycles/experiments, a set of five scientific articles were written, submitted, and four out of the five papers have already been published[1]. The five single research papers can be found in the subsequent section (chapter 6-10). Next to the scientific papers, the gained insights were recurrently presented at research colloquia, practitioner's conferences, and network meetings to share the outcomes and integrate feedback from corporate perspectives. This dissertation finally closes the ADR performance by articulating the accumulated learnings in the light of research and theories, which accordingly formalizes the findings on an established VDT approach and responding to the research questions (chapter 11).

[1] The subsequent five research papers do only differ from their original publication with regards to format and minor changes in language to adhere to American English spelling.

6. Paper 1

Shared Mental Models in Creative Virtual Teamwork

Authors: Beke Redlich, Dominik Siemon, Christoph Lattemann, Susanne Robra-Bissantz

This paper by the above-mentioned authors was published in the Proceedings of the 50th Hawaii International Conference on System Sciences (HICSS) 2017 and can be found here: http://hdl.handle.net/10125/41206.

6.1 Abstract

This paper presents an experiment on the impact of Shared Mental Models (SMM) on creative virtual teamwork. We tested whether the usage of an online whiteboard influences the building of SMM in the initial phase of virtual teamwork. As SMM are the foundation for successful collaboration in teams, we transferred the construct on measuring the team task and team goal in a creative virtual team process. In the first section of the paper a theoretical discussion on SMM, creativity, and virtual teamwork will be presented. Subsequently, our experiment on virtual teamwork via the use of a virtual tool and its impact toward SMM will be introduced and the results will be discussed. We identified that specific creative competencies of virtual tools enhance the level of SMM but still lack in perceived efficiency compared to physically present teamwork. The findings recommend further research on the applicability, effectiveness and capabilities of creative virtual tools.

6.2 Introduction

Fostering creativity, developing innovative products and services as well as solving complex tasks are current challenges in daily business life. Various creative innovation approaches, such as Design Thinking, have been developed in the past decades to provide a method to solve these challenges. A fundamental element of these methods is teamwork in diverse working areas.

Within changing business environments due to technological achievements, teamwork can be performed time- and location-independent on a virtual level by the use of Information and Communication Technology (ICT). Virtual Teams are confronted with different challenges than face-to-face teams concerning for instance the remote understanding of the overall task that has to be solved.

Past research has shown that Shared Mental Models (SMM), on a face-to-face level, are crucial for the success of a team (Santos et al. 2015). SMM relate to a collective comprehension between all individuals in a team concerning several aspects of teamwork such as tasks, goals and skills (Santos et al. 2015, de Vreede et al. 2012). In this paper, we will discuss the impact on SMM within virtualized collaboration.

Transferring and analyzing the results in research already conducted in the area of SMM, creativity, and virtual teams, we aim to initialize a scientific discussion on the building of SMM in virtual team environment concerning the use of visualization. Namely, we test the influence of and on SMM when using a virtual visualization tool as a teamwork facilitator. With our conducted experiment, we identified that virtual teams, using visualization tools, work more effective and satisfied and can build a higher shared understanding.

In the first section of this paper a theoretical foundation of SMM and virtual teams will be presented and discussed in the context of using ICT that supports the visualization of a SMM. Following, the assumptions and hypotheses will be presented and the research experiment will be introduced.
In the second section the methodological approach of the experiment will be described in detail and the results will be presented subsequently. The third and closing section of this paper discusses the experiment's results followed by the conclusion.

6.3 Context

This study is part of a larger project in which we analyze the effects on and the chances of SMM in a Virtual Design Thinking process. Design Thinking is inherently based on teamwork and comprises creativity, multidisciplinarity, collaboration, co-creation and iteration. Design Thinking uses tools in a sequence, borrowed from different scientific disciplines like Social Sciences (e.g. Psychology and Economics), Design Sciences (e.g. Architecture) and Engineering (e.g. Computer Sciences, Mechanical Engineering). In the past years various tools were developed as a digitized version and are offered online (e.g. www.mural.co). There is a high number of virtual tools with a vast variety of functionalities and application areas. Despite the vast presence and use of online tools, which may support a Virtual Design Thinking process, there is no complete reproduction of a whole face-to-face Design Thinking process available yet. Well-developed, scientific-based approaches for 'Virtual Design Thinking' are missing.
Our motivation for this paper comes from a Design Thinking perspective, which explains several aspects included in our paper, e.g. the debate on wicked problems in a virtual creative teamwork. Nonetheless, we firstly focus on the role of SMM in creative virtual teams.

6.3.1 Shared Mental Models

Shared Mental Models (SMM) are psychological constructs and describe the accumulation of diverse Mental Models represented in a team. Each individual has made up a mental model in order to synthesize the diverse facets a person acts in. Mental models are defined as individual cognitive displays relating to one's specific structures as foundation for interaction (Resick et al. 2010, Rouse and Morris 1986). On the one hand, a mental model helps to explain individual's decision making. On the other hand, the understanding of mental models reveals the needs of individuals to perform in specific situations.
Whereas mental models refer to the individual level of humans, the concept was transferred to a team level – the accumulation of different mental models represented in a group. The so called Team Mental Model reveals a common comprehension between individuals in a team concerning specific facets on occupational concerns such as task, performance, and interaction (Cannon-Bowers et al. 1993, Cannon-Bowers and Salas 2001, Resick et al. 2010, Rouse and Morris 1986). One focus of Team Mental Models are resemblances of mental models – Shared Mental Models (Cannon-Bowers et al. 1993, Cannon-Bowers and Salas 2001, Mohammed et al. 2000, Resick et al. 2010). SMM in research have been theorized with different foci whereas the emphasis has

developed strongly toward the joint comprehension shared by all members in a team while different mental models are existent (Klimoski and Mohammed 1994, Maynard and Gilson 2014, Santos et al. 2015). This refers to the congruent development of SMM that is needed for successful collaboration (Klimoski and Mohammed 1994, Lim and Klein 2006). Furthermore, SMM embody knowledge structures that unite individuals in a team (de Vreede et al. 2012). The shared structures of SMM lay open a path on how individuals may perform as a team in their surrounding (de Vreede et al. 2012). de Vreede et al. (2012) collated the following structures of SMM that are split into four categories: Firstly, knowledge structures on equipment and tools; secondly, team task, goal, and performance requirements; thirdly, knowledge about other team members' abilities, knowledge, and skills and fourthly, knowledge about appropriate team interactions (de Vreede et al. 2012). Past research often focused on one of the above-mentioned categories (de Vreede et al. 2012). Moreover, the purpose of SMM are to enable the members of one team to build upon their own knowledge structures as a pathway finder on interaction with team members as well as forecast on knowing how to process as a team (Mathieu et al. 2000).

6.3.2 Shared Mental Models and Creativity

One major aspect in SMM research is the relation between SMM and creativity. The ability of being creative in a team is defined as generating novel ideas, which lead to innovative products and services as well as processes in order to reach the organization's objectives in an improved manner (Amabile 1988, Burke et al. 2006, Santos et al. 2015). This also resembles the idea of innovation methods such as Design Thinking. Within SMM research a debate on whether SMM foster or tackle creativity has been discussed over the past years (Santos et al. 2015). Scholars who assume a negative effect of SMM on creativity claim that a high proportion of SMM hinder creativity. This is because over a longer period of time the harmonization of SMM leads to a comfortable position that is barely risked (Burke et al. 2006). The situation of high SMM in teams could lead to avoidance of conflict which is related to a restriction in solution space that might hinder creative and innovative results (Burke et al. 2006, Santos et al. 2015). It has to be outlined that the argumentation is connected to the lifespan of a team. Meeting in always changing team constellation might turn the described effects. The study of Santos et al. (2015, p. 653) states that empirical research on the influence of SMM on creativity is still missing but their own study did a convincing contribution in presenting that SMM 'positively influences team creativity, and in turn team effectiveness.'. It has been determined that the SMM categories such as team processes, communication patterns, and task orientation have a positive effect on creativity (Santos et al. 2015). Likewise, Santos et al. (2015) concluded that SMM in a team leads to generating new ideas transferred onto new products (or services), which suit the demands and necessities of task and team. Accordingly, teamwork supported by SMM result in satisfaction of the individual and convincing standard of enactment (Santos et al. 2015). Scholars who claim that SMM have a positive effect on creativity state that the ability of adaptation either on sharing mental models or being commonly creative resemble each other as both aspects solve problems (Burke et al. 2006, Santos et al. 2015). Accordingly, SMM represent the team member's ability to foreshadow the desires and activities of team colleagues in order to familiarize and by that perform interactions that are positive for teamwork, -processes, -tasks, and -goals (Cannon-Bowers et al. 1993, Santos et al. 2015). The following section will describe the relationship between SMM, creativity, and virtual teams.

6.3.3 On Teamwork, Virtual Teams, and Shared Mental Models

Teamwork has become an integral part of daily business life that cannot protect itself from changing business environments: Originally teamwork was based on the physical presence of team members but since the enhancement of ICT, teamwork can be performed location-independent on a virtual level (Maynard and Gilson 2014). Maynard and Gilson (2014, p. 2) go even a step further in stating that 'today's teams rely extensively, and sometimes even exclusively, on technology to communicate'. This development might even increase since the quality, competencies, and variety of ICT will probably rise, and this is indispensably connected to changes in working structures. Existing research on the impact of ICT on teamwork is limited but current studies show that the application of ICT in team contexts can either result in positive, negative or neutral effects on team performance (Maynard and Gilson 2014).

Teamwork in general implies three major aspects such as working interdependently with other members, incorporating the ability to adapt to demands of team members and team task, dynamic communication as well as information transfer and adapting toward a certain lifespan of a task that has to be solved commonly (Salas et al. 2000). Teamwork is part of diverse occupations and can even be performed without the physical presence of team members, hence in virtual teams. Virtual teams have been defined as teamwork that is based on technology-mediated communication while crossing several boundaries (Kirkman and Mathieu 2005) and rely on a certain degree of the usage of virtual tools in order to organize and perform a team process (Maynard and Gilson 2014).

Due to the advanced settings of virtual teams in comparison to face-to-face teams particular challenges influence the functioning of virtual teams. Maynard and Gilson (2014) determine that the common comprehension of a team task developed via SMM is a prerequisite for successive team performance, no matter what kind of communication is chosen (Maynard and Gilson 2014). Working virtually in a team implies an advanced challenge for each team member due to time and timing aspects. On the one hand, when using virtual tools the current person in charge has to comprehend what the person/people did previously and what can be done now in the context of the overall team task – time-independence relates to task interdependency (Maynard and Gilson 2014). On the other hand, virtual teams might foster simultaneous collaboration that needs to be organized in terms of time and timespan.

6.3.4 Shared Mental Models in Virtual Teams

Until now, most research has focused on building SMM and their effects on given aspects in physically present teams but there is still a lack in research on SMM in virtual teams (Maynard and Gilson 2014). However, the findings already made will be used as a basis for our paper. Within the research on the role of SMM in virtual teams, Maynard and Gilson (2014) investigated the effects of technology used by virtual teams on SMM, more specifically on the SMM knowledge structures team and task. They found out that the proposed SMM knowledge structures can be similarly treated in face-to-face teams and virtual teams, as both need to have a common comprehension of what to do (task) and how to organize their activity (process) (Maynard and Gilson 2014). Furthermore, the authors identified that technology used by virtual teams can either impede or support the building of SMM. This is due to the fact that SMM are built in phases, which is influenced by the choice and use of virtual tools/technology in virtual team processes (Maynard and Gilson 2014). Accordingly, the choice of virtual tools concerning their competencies has a tremendous effect on SMM (Maynard and Gilson 2014). These findings lead to our assumption that a further examination on specific virtual tools and their role toward SMM needs to be conducted. The foundation for building SMM in virtual teams is appropriate communication that facilitates a shared task comprehension as starting point for a common team process (Mathieu et al. 2000).

6.3.5 Wicked Problems, Visualization, and Shared Mental Models

Buchanan (1992) presented a paper on 'Wicked Problems in Design Thinking' in which he outlined that problems, which are indefinite and with no way toward fast solution can appropriately be solved in the way designer think, hence with Design Thinking, which can be transferred on a general creative approach to solving wicked problems (Johansson-Sköldberg et al. 2013). Although slightly different in definition, the so-called complex problems have already been identified in SMM research. In the past decades research on Complex Problem Solving (CPS) has been established within the area of Psychology (Funke 2009). A CPS is defined as process where a sequence of tasks are needed to come to a result – challenges are: complexity (several requirements influence clarification), connectivity (interconnectivity of events and aspects), dynamics (changing events and requirements), and no transparency (the given events are not predictable) (Dörner and Bick 1983, Funke 2009). When teams are confronted with complex problems, the establishment of SMM is advantageous, as the ability on adaptation is highly demanded in this context. Since past research has shown that SMM, more specifically the ability toward adaptation, have a positive effect on solving complex problems, we propose that SMM also have a positive effect in solving wicked problems. This proposition refers to the similar interdependent structure of both complex- and wicked problems and that the competence of adaptation within a team remains the same challenge in both processes.

One way to achieve SMM in wicked problem environments is visualization. Visualization is used in multiple occasions to facilitate creative teamwork. Various research already examined the usage of visualization tools as structural support for individual or collaborative knowledge construction. Visualization can be effectively used to represent individual opinions in order to support reasoning. Visualizing a mental model can therefore help to express complex thoughts (Fischer et al. 2002). Findings show that especially in an early stage of a problem-solving task, the process and the outcome can be improved by providing people with the possibility to visualize their thoughts (Blaser et al. 2000a, Fischer et al. 2002). Using visualization to enhance SMM has been identified as a suitable approach to support collaborative learning, negation, and decision making as well as to promote group consensus (Landman et al. 2009, Swaab et al. 2002). In collaborative visualization, the visual representation of individual mental models is challenging. Due to different opinions, cultures, background, interests, and paradigms (Landman et al. 2009), the building of SMM can cause problems in communication and cooperation, which can result in an ineffective team performance (Kolkman et al. 2005, Landman et al. 2009, Mathieu et al. 2000). This requires a suitable tool to head toward a visual representation of a SMM. We focus on the measurement of the effects of visualization and especially of virtual collaborative visualization of a wicked problem on SMM. We additionally aim to measure the effectiveness and satisfaction level of a virtual visualization tool used in a collaborative process to identify novel and effective types of ICT to support this process.

Yusoff and Salim (2015) identified five types of visualization on a virtual team level: shared - and shared coordination visualization, shared multiple representation, and shared mirroring display –

each type has effects on SMM. Shared visualization is utilized to envision content, process, and artifacts within a team process in order to foster SMM (Yusoff and Salim 2015). The visualization type shared mirroring display supports collaboration within interrelated tasks whereas shared multiple representation collates different visualizations for collaboration, which can be advantageous for solving wicked problems. All of these categories refer to different kinds of visualization concerning methodology, collaboration, complexity, etc. Yusoff and Salim (2015) examined the type of visualization concerning competencies of specific technologies, our focus is the investigation of the effect on SMM when using virtual visualization in teams.

6.4 Methodology

The description and discussion of theoretical backgrounds, common roots, and relation between SMM, creativity and virtual teams show a common ground for research on specific virtual tools to further investigate and improve creative virtual teamwork.

In this paper, we test the impact of the use of a virtual tool, in particular visualization, on SMM in teamwork. With this research aim, we follow the suggestion from Maynard and Gilson (2014) who proposed that research on SMM in virtual teams would outline the effects of individual reaction on different technologies and help to explore the application of innovative IT and its effect on SMM and enactment of virtual teams.

As starting point to our research aim, we begin to test how SMM can be ideally build in virtual teams in the initial phase of creative teamwork. We analyze, if visualization can improve a shared understanding of a given problem in virtual teams.

We set up an experiment to examine the usage of a virtual tool that supports the interactive and collaborative building of a visual representation of a given problem (DeLone and McLean 1992, Keppel 1991, Nunamaker et al. 1990).

Our objectives are to answer the following research questions:

(1) How do individuals adapt given technologies to fit their needs (Maynard and Gilson 2014)?
(2) What novel types of ICT can be used to enhance the development of SMM and support virtual team performance?

For a comprehensive analysis, we thus evaluate if our chosen virtual tool provides an effective way of dealing with a wicked problem, as well as the level of satisfaction and the way, how the interaction was structured. As teams, 'which members structure and organize their team related knowledge' tend to easily coordinate their activities and thus improve their team performance, we additionally assess the effectiveness of the virtual tool and the structure of their interaction (Lim and Klein 2006, p. 413, Link et al. 2015). We derive the following three hypotheses to evaluate the effects of our proposed virtual tool. A virtual visualization tool that offers a variety of visualization features, bears

(H1) a higher level of shared understanding of a team task and a team goal …
(H2) a higher level of satisfaction …
(H3) a higher level of perceived effectiveness …
(H4) a more structured team interaction …

… in comparison to a system without the functionality of visualization.

In order to validate our hypotheses, we conducted an experiment with two groups that used different virtual tools. Our experimental group used an online whiteboard – originally designed to support Design Thinking – called *Spacedeck* (www.spacedeck.net). Spacedeck is a virtual collaboration tool for visualization, with specific competencies such as the possibility to draw or insert text, forms, and multimedia like audio-, video-, and image files. The whiteboard has an intuitive functionality and its collaboration can be performed in real-time with multiple geographically dispersed users. Additionally, a chat function supports communication within virtual teams. Spacedeck has been developed to support especially creative work in creative projects and enterprises for visual collaboration (Güther and Hartmann 2017).

Whiteboards play an important role in creative teamwork processes since its plain surface is used for visualization of tasks, ideas, images, and other methods. In physically present teams a whiteboard is a support to visualize while communication proceeds and non-verbal signs influence the interaction (Hartmann et al. 2010, Wood and Ashfield 2008). For that reason, we chose the online whiteboard *Spacedeck* since its functionalities come close to a physically present environment. In contrast, the control group used a simple chat system without having the possibility to visualize their thoughts.

6.4.1 Experiment Structure

We conducted an experiment with 40 participants, which involved undergraduate and graduate students in the ages between 22 and 30. The participants were students with majors in the fields of Computer Science, Technology-oriented Business Administration, Engineering, and other technological studies. In the beginning, the participants were randomly and blindly assigned to either an experimental (EG) or control group (CG). We included a total of 10 teams (5 experimental teams, 5 control teams) with 4 team members each, as larger team sizes are less likely to build SMM (van den Bossche et al. 2010). Overall, we had 34 male and 6 female participants. Both groups were assigned to collaboratively engage with the same given task. For the purpose of the experiment, we used a wicked problem that all team members should commonly understand in order to be able to formulate a team process. Wicked problems have a high number of elements that are relevant to the solution process and are interconnected. Wicked problem solutions can be evaluated as good or bad but there is no right or wrong, there is no similar approach to solution adapted from other problem solving processes, there are several explanations due to ideology, wicked problems are dependent to other (complex) problems, there is just one chance for success and no failure allowed (Buchanan 1992, Funke 2009). For our experiment we used the wicked problem of radioactive waste, including its origin and handling. The problem of nuclear waste is a commonly known issue, frequently discussed in the media with many views and concerns. Our defined problem contained 28 elements like nuclear fission, uranium mining, tailing, nuclear medicine, nuclear reprocessing, and interim storage. The problem had no definite formulation, had no stopping rule, had a highly nontransparent structure with a variety of connections, influences, different possible goals, and confusing information (Buchanan 1992, Funke 2009). However, the structure and relations between each element (e.g. 'uranium mining leads to tailing') was explained in a textual description.

Both groups had the same textual description of the problem, whereat the experimental group used the online-whiteboard tool to be able to further visualize the problem. Both groups were given a chat function that should be used for communication within the teams. The teams had

20 minutes to collaboratively deal with the problem by using the given functions. Experiments with test groups, prior to the experiment, showed that the participants tended to finish working on the wicked problem after about 20 minutes. Hence, we determined a 20-minute timeframe for the group work. Additionally, no participant in our experiments asked for additional time. Both groups had the same instructions: first, deal with, and understand the problem; second, find a common goal and reach agreement. The teams were not asked to produce ideas at this very beginning of a teamwork process. Both groups were introduced to the tools four days in advance, to get familiar with the functionality. After the process, each team member received a survey to individually rate the level of SMM, perceived effectiveness, satisfaction, and the way the team interacted. On the one hand, these questions provide us feedback on the effect on SMM when the support of visualization in virtual teams is given. On the other hand, by evaluating the survey we can outline whether visualization in virtual teamwork is able to keep up in terms of perceived effectiveness, satisfaction, and interaction in comparison to physically present teamwork. Both, the survey and the experiment data will provide us indication on first, the effect on SMM within the experiment structure and second, whether the chosen virtual visualization tool can appropriately serve as replacement for physically present teamwork in the initialization phase of a creative teamwork.

6.4.2 Measures

To validate our hypotheses, we disposed four dependent measures. Our measure, *shared understanding of team task and goals,* contains 21 unweighted items from Johnson et al. (2007) and Santos et al. (2015), that are rated on a 5-point Likert-scale. Our second measure, *satisfaction*, evaluates the level of satisfaction of the participants with the tool. It contains 7 unweighted items from Dennis et al. (1996) and Santos et al. (2015) and is rated on a 5-point Likert-scale. The third measure involves the *perceived effectiveness* of the process and contains four unweighted items, rated on a 5-point Likert-scale. The last measure, *structured interaction,* evaluates, how well structured and goal oriented the discussion was and how the communication in the team was perceived. The measure contains five unweighted items from Alrushiedat & Olfman (2012), and van der Pol et al. (2006), with different rating scales. Table 1 shows the measures, which were captured in a post-process survey.

Measure	Items	Scale range
Shared understanding of the team task and goal	21	1=Strongly Agree; 2=Agree; 3=Undecided; 4=Disagree; 5=Strongly Disagree
Satisfaction	7	1=Very satisfied; 2=Satisfied 3=Neither; 4=Dissatisfied; 5=Very dissatisfied
Perceived effectiveness	3+1[1]	1=Very effective; 2=Effective; 3=Neither; 4=Ineffective; 5=Very ineffective
Structured interaction	3+2[2]	1=Strongly Agree; 2=Agree; 3=Undecided; 4=Disagree; 5=Strongly Disagree

Table 1 Paper 1 – Measures

[1] The item 'How effective was this meeting compared to a face-to-face meeting.' is excluded from the mean and t-test calculations.
[2]The measure structured interaction contains two questions, which are excluded from the mean and t-test calculations due to an inverted scale and a neutral loading: Question 1: 'The discussion was factual, not personal nor critical.' and question 2: 'Many explanations were necessary during the process.'
In addition, we capture the whole communication process of each team. We further compute the mean of the number of words used for communication to find out if SMM need intensive direct communication or if SMM can be built on a mix of communication and visualizing of the given wicked problem.

6.4.3 Results

The survey resulted in overall 1480 ratings by 40 participants. We calculated the means and standard deviations of every measure and computed a set of two sample t-tests to validate our hypotheses. Table 2 shows the results of the experiment.

Measure	Means	SDs
Shared understanding of the team task and goal	$\bar{x}_{EG}$=1.919 $\bar{x}_{CG}$=3.548	σ_{EG}=.837 σ_{CG}=.940
Satisfaction	$\bar{x}_{EG}$=2.050 $\bar{x}_{CG}$=3.436	σ_{EG}=.916 σ_{CG}=.969
Perceived effectiveness	$\bar{x}_{EG}$=2.233 $\bar{x}_{CG}$=3.700	σ_{EG}=.698 σ_{CG}=.788
Structured interaction	$\bar{x}_{EG}$=1.917 $\bar{x}_{CG}$=3.183	σ_{EG}=.743 σ_{CG}=.983

Table 2 Paper 1 – Results (Experimental Group: EG; Control Group: CG)

The two sample t-tests validate our hypotheses. Shared understanding of the team task and goal is significantly higher in the experimental group (mean=1.919) than in the control group (mean=3.548, t=25.527, p=2.2e-16, df=838). Satisfaction is significantly higher in the experimental group (mean=2.050) than in the control group (mean=3.436, t=12.298, p=2.2e-16, df=278). Perceived effectiveness is significantly higher in the experimental group (mean=2.233) than in the control group (mean=3.700, t=10.796, p=2.2e-16, df=118) and structured interaction is significantly higher in the experimental group (mean=1.917) than in the control group (mean=3.183, t=7.9633, p=1.165e-12, df=118).
Both groups stated that the discussion was factual, not personal nor critical ($\bar{x}$EG=1.450; $\bar{x}$CG=1.800), but also stated that many explanations were necessary during the process ($\bar{x}$EG=2.400; $\bar{x}$CG=2.250). Both groups, however, stated that the process was not as effective as a face-to-face meeting ($\bar{x}$EG=3.450; $\bar{x}$CG=4.000). The experimental teams used on average 260 words for their group interaction, whereas the control teams used on average 514 words. Every experimental group came up with a comprehensive figure of the wicked problem, containing every important element of the problem construct. Figure 1 shows the produced visualization of the wicked problem of one experimental team.

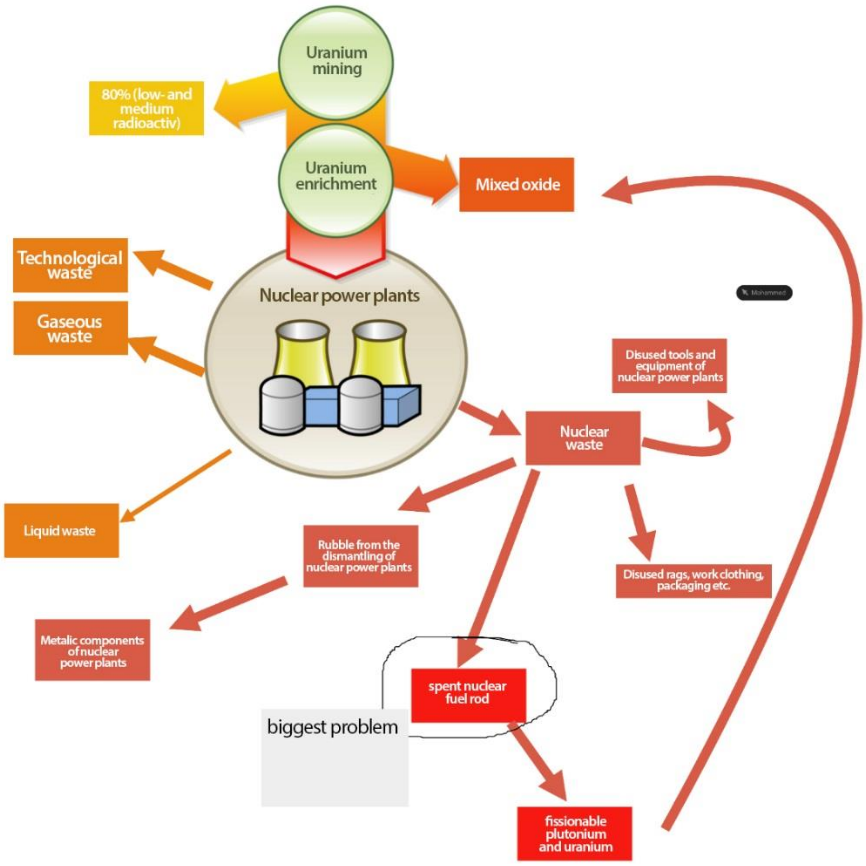

Figure 17 Paper 1 – Visualization of the wicked problem produced by an experimental team (translated into English)

6.5 Discussion

With our experiment we aimed to evaluate the applicability of an online-whiteboard to build a shared understanding of a team task and a team goal within virtual teams. In addition, we evaluated whether the online-whiteboard offers an appropriate way to collaboratively deal with a given task, whether it supports a more structured interaction and whether it leads to a satisfied usage. Our experimental teams who used the online-whiteboard outperformed the control teams that did not have the functionality of visualizing their thoughts. The experimental group had a significant higher shared understanding of the team task and team goal, a higher perceived effectiveness, a higher level of satisfaction, and a more structured process. The given results present a significantly higher SMM when visualization is used in virtual teamwork. This supports the assumption that SMM work as a proper indicator for creative virtual teamwork. However, both groups stated, that using the virtual tool is less effective than a face-to-face teamwork. Face-to-face situations offer several more possibilities for communication, interaction, and knowledge sharing in comparison to the limited competencies of our web-based virtual tool (Warkentin et al. 1997). Even though, we identified a significant difference between two virtual tools, we did not intend to establish a virtual tool to outperform face-to-face meetings. In fact, the results show that a virtual tool can even impede SMM as already mentioned by Maynard and Gilson (2014).The teams of the control group used on average more words during their discussion. This is due to the fact, that they needed more words to describe the problem, as there was no other way of collaboration like visualization. In addition, they spent more time discussing their procedure, whereas the experimental teams started working faster. Although, both groups reported that many explanations during the experiment were necessary, the qualitative analyses of the chat history showed, that only the control group discussed the interconnections, influences, and the structure of the wicked problem. Whereas the experimental group mainly discussed the usage of the tool. These findings give answer to our research question how individuals adapt to given technologies to fit their needs. The control teams had only one possibility to collaborate via the use of the chat function – the qualitative evaluation of the chat history outlined that team members concentrated on task relevant communication, which underlines that given technology was adapted toward team task and team goal related needs. In contrast, the experimental group adapted the chat function for team process relevant communication such as the functionality of the tool, since the opportunity to visualize substituted team task and goal-oriented chat-communication. But it has to be considered that the small number of participants limits the generalizability of the results. However, our experiment shows that an online-whiteboard offers an appropriate way to build SMM. This is the answer to our second research question, asking what novel types of ICT can be used to enhance the development of SMM and support virtual team performance. Our chosen virtual tool is relatively new and its abilities come close to the abilities of physically present teams (visualization in form of text, images, communication and collaboration).

6.6 Conclusion and Outlook

As customers, business partners, employees, and other stakeholder are increasingly dispersed around the globe, creative team processes must be adapted toward a virtual, time- and location-independent process via the support of ICT. We started our research by firstly identifying virtual tools that support the development of SMM, which are the basis for collaborative work and hence the founding pillar for creativity and innovation methods. By assigning existing virtual tools on their application within a creative process, we decided to focus on the initializing phase. Furthermore, we decided to use an online-whiteboard as appropriate virtual tool. The functionality of a (online) whiteboard offers the possibility to start from a plain surface to arrange necessary aspects, questions, and interdependencies until a wicked problem is appropriately illustrated. This reveals a common understanding of a team task, goal, and process via collaboratively visualizing in a virtual team. SMM act as indicator for successive teamwork. This paper shall act as a starting point toward improving creative virtual teamwork via the usage of SMM as proving indicator. To reach the goal of virtually performing creative processes, a multiplicity of aspects such as synergies and visualization competencies need to be protected and technological requirements for creative virtual teamwork need to be aligned and improved according to teamwork processes, e.g. collaboration and usability.

Our experiment has shown that virtual visualization of a wicked problem increases the level of SMM and its perceived effectiveness by members in a virtual team. The combination of SMM, virtual teams, creativity, and wicked problems revealed a foundation for time- and location-independent teamwork with the help of ICT and, thus, initializing a first step toward 'Virtual Design Thinking'.

The next step in our research is to improve the performance of virtual tools in a way that their use is as efficient as face-to-face teamwork. To increase the quality, efficiency and satisfaction of virtual creative processes, further investigation on the usage of ICT and virtual tools for the initialization phase as well as the following team process phases need to be conducted. We

suggest analyzing different types of virtual visualization tools as well as other tools that support creativity to prove their competencies and impact on SMM in a creative teamwork context.
Further on, our experiment focused on the two SMM knowledge structures team task and team goal, for more detailed results other knowledge structures such as knowledge about abilities, competencies, and skills of team members could be taken into account via the application of social media profiles. Furthermore, we suggest an experiment environment with diverse cultural backgrounds of participants to investigate the effects of culture and SMM in virtual creative teamwork. Additionally, we suggest the investigation of other creative methods for visualization than whiteboards to enhance team performance.

6.7 Acknowledgements

This paper is part of a project called DETHIS – Design Thinking for Industrial Services, funded by the German Federal Ministry of Education and Research (BMBF); Grant # 01FJ15100.

7. Paper 2

Forming Virtual Teams – Visualization with Digital Whiteboards to Increase Shared Understanding, Satisfaction and Perceived Effectiveness

Dominik Siemon, Beke Redlich, Christoph Lattemann, Susanne Robra-Bissantz

This paper by the above-mentioned authors was published in the Proceedings of the International Conference on Information Systems (ICIS) and can be found here: https://aisel.aisnet.org/icis2017/SocialMedia/Presentations/9/.

7.1 Abstract

To achieve effective virtual teamwork, suitable ICT that effectively support the formation of virtual teams must be identified. This paper presents an experiment on testing how to increase shared understanding, satisfaction, and perceived effectiveness in the forming phase of virtual teamwork. We applied the psychological construct of Shared Mental Models (SMM) - more specifically the knowledge structure team task, goal, and performance requirements - to evaluate whether the collaborative visualization of a wicked problem with a digital whiteboard can support team members in building SMM. Our results from the experiment reveal that the usage of a digital whiteboard positively affects team interaction, satisfaction, structure, and understanding and hence, team performance. Furthermore, the results support findings from prior research that richer media, which allows for synchronicity within communication enhances the communication process.

7.2 Introduction and Motivation

Innovations in Information and Communication Technology (ICT) constantly change corporate communication and collaboration. ICT-based, location-independent teamwork influences business routines and collaboration patterns (Lurey and Raisinghani 2001). The physical and geographical dispersion of companies and workers is no longer a barrier for collaboration (Lurey and Raisinghani 2001). However, virtual teamwork requires different tools and mechanisms than face-to-face teamwork. Virtual teamwork can be performed in different settings and for different purposes, which leads to the adaptation and development of specific tools for the interaction among humans and computers (Raghuram et al. 2009). Teamwork is generally not limited to any occupation, division, or organization, which indicates the relevance of the topic for diverse areas (Salas et al. 2000). Workers are constantly confronted with new and challenging tasks and tools (Schouten et al. 2016), thus changing work habits, tasks, and performance (Lurey and Raisinghani 2001). To achieve effective virtual teamwork, the interdependences of individual workers, teams, ICT, and tasks must be understood (Bartelt and Dennis 2014, Kanawattanachai and Yoo 2007, Lurey and Raisinghani 2001). Identifying suitable means to effectively support the formation of virtual teams would make a significant contribution to the knowledge base on virtual teamwork and will also enhance existing literature. Furthermore, the research would allow practitioners to implement adequate visualization tools, because '[a] well-designed team-based organization can expect to see better problem solving and increased productivity, effective use of company resources, better quality products and services, increased creativity and innovation, and higher quality decisions.' (Lurey and Raisinghani 2001, p. 542).

In this contribution, we raise the following research question: can ICT, which enable collaborative visualization, enhance the effectiveness of virtual teams in the 'forming' phase of projects? In the forming phase, team members build a common understanding and knowledge of the underlying tasks, goals, and intentions (Tuckman 1965). Effectiveness, in the context of this paper, relates to the individual perception of team members' shared comprehension of team task, goal, and processes, as well as their perceived satisfaction. We conducted an experiment where virtual teams visualize their tasks collaboratively to understand a wicked problem in order to initiate a team process. The term 'wicked problem' can be traced back to Buchanan (1992). Wicked problems are indistinct, have innumerable causes, have no right solution and are solved in the way designers think (Buchanan 1992). The designer's perspective indicates a visual approach to solve wicked problems. To evaluate the applicability and effectiveness of our virtual tool from a human-centered perspective, we used the measurable psychological construct of Shared Mental Models (SMM).

In the first section of this paper, we will discuss the overall challenges of (virtual) teamwork as well as those found in the forming phase. We will also reflect on given media theories such as Media Naturalness Theory (MNT), Media Synchronicity Theory (MST), and Media Richness Theory (MRT). Secondly, we will outline the concept of visualization in regard to digital whiteboards. Thirdly, we will discuss the role of SMM in the context of visualization and wicked problems, as well as introducing our propositions. Fourthly, we will concentrate on the methodology and explain our artifact (i.e. the virtual tool), our experiment, our survey, and our results (Hevner et al. 2004). Fifthly, we will discuss our results in regards to findings mentioned in relevant literature. Within the conclusion, we reveal that our artifact, the virtual tool for collaborative visualization of wicked problems, increases the level of SMM, including an increased satisfaction level, and an increased perceived effectiveness by team members.

7.3 (Virtual) Teamwork and the Forming Phase

7.3.1 Characteristics and Phases of Teamwork

The term 'team' is defined as a group of individuals who work collaboratively with a shared intention in order to reach a specific target (Lurey and Raisinghani 2001). In past research, specific characteristics of teamwork have been discovered: firstly, team members are supposed to work independently and collaboratively, in a manner that needs to be coordinated and harmonized (Salas et al. 2000). Secondly, the team environment is changing due to task and team settings, which demands revaluation and adjustment for team tasks and processes, which are highly connected to communication. Thirdly, the dynamic exchange of team- and task-relevant information is one of the challenges of teamwork. Fourthly, teamwork is characterized by always having a limited time span as well as a shared vision.

Tuckman and Jensen (1965, 1977) determined the following phases of teamwork: forming, storming, norming, performing, and adjourning. The forming phase is characterized as an orientation through testing the constraints of behavior toward tasks, members, and leaders, which is followed by building interdependencies that are highly connected to team building processes. As such, the forming phase is an inevitable phase for collaborative teamwork, where, among other things, a SMM is constructed and the basis for the following collaborative process is established. The storming phase is characterized by conflicts and polarization, followed by norming, where new standards arise and interpersonal roles are set. In the performing phase, teams channel their ambitions toward team tasks and team goals (Tuckman 1965). The adjourning phase closes and dissolves teamwork (Tuckman and Jensen 1977).

7.3.2 Media Theories – Challenges and Opportunities of Virtual Teamwork

When comparing virtual and face-to-face teams, advantages as well as disadvantages of virtual teams can be found. In contrast to face-to-face teams, virtual teams challenge the interplay of verbal- and non-verbal communication in physical surroundings (Schouten et al. 2016), which limits the visual perception of human and environment interaction (Bartelt and Dennis 2014, Kanawattanachai and Yoo 2007). The Media Naturalness Theory, which builds on human evolution ideas, posits that the use of communication media suppresses key elements found in face-to-face communication, which ends up posing cognitive obstacles for communication (Kock 2004). This is particularly the case in the context of complex tasks (Kock 2004).

It has to be outlined that virtual teams are enabled for multichannel-communication in comparison to one-channel face-to-face conversation, e.g. communication in forums and simultaneous connection of team members via phone, video-chat, etc. (Schouten et al. 2016). In this context, the Media Synchronicity Theory posits that communication will be enhanced when the synchronicity of a given medium can appropriately support the synchronicity that a communication process requires (Dennis et al. 2008, Dennis and Valacich 1999). The MST focuses on the capability of media to support synchronicity, which is defined as a 'state in which individuals are working together at the same time with a common focus' (Dennis et al. 2008, p.581). Hence, virtual teams are dependent on electronic devices, which causes restrictions in resource access, e.g. internet and specific software access, but also leading to the opportunity of quickly presenting visual material such as data, graphs, and photos, among other things (Schouten et al. 2016). In this regard, the Media Richness Theory explains that richer, personal communication media is generally more effective for communication of equivocal issues than leaner, less rich media (Daft and Lengel 1986). This dependence and likewise opportunity forces virtual teams to apply ICT (Hollan et al. 2000).

In addition, ICT facilitates the creation of virtual teams without boundaries of specific areas or disciplines, which results in multidisciplinary teamwork and fitting competencies of team members due to team tasks and requirements (Thomas and Bostrom 2007). Furthermore, virtually performed teamwork enables flexibility in terms of tasks, schedules, and team formation, as well as an adaptation of working life in organizations (Lurey and Raisinghani 2001).

In the forming phase of teamwork, a common understanding and knowledge of the underlying tasks, goals, and intentions by team members need to be developed. This is a challenge since virtual teams naturally have performing restrictions in the forming phase, as communication channels are limited due to the functionality of the applied ICT (Kirkman and Mathieu 2005, Thomas and Bostrom 2007, Warkentin et al. 1997).

7.4 Virtual Visualization as Teamwork Facilitator

According to the MRT, there is a need for a tool that allows rich and personal communication. Additionally, the tool should support synchronous communication to fulfil the requirements of the communication process. In our research, we introduce the concept of 'visualization' to support the forming processes of teams. In the given context, visualization can be understood as a part of a Creativity Support System (Gabriel et al. 2016, Shneiderman 2007), which fosters the development of mental images (Rouse and Morris 1986) and builds the basis for various creativity techniques (Resick et al. 2010).

7.4.1 The Concept of Visualization

Generally, the concept of visualization inherits an internal and external scope, whereas internal representation means 'to form a mental image of' a given content and is understood as a cognitive process, and external visualization refers to tangible visual representation of given content (Santos et al. 2015, p. 1, Ware 2012). On an individual level, an internal representation can be transformed to an external visual artifact to support reasoning (Ware 2012).

In terms of teamwork, several mental images/models need to adapt to team task, goal, and requirements. In order to create a shared understanding of several single mental models, a collaborative development of one external visualization supports reasoning and progress (Swaab et al. 2002). Furthermore, the possibility to visualize content supports gaining insights for a deeper understanding, better explanation, and for the development of groundwork for decisions (Liu et al. 2008).

In an experiment by Fischer et al. (2002) on the support of visualization in team learning processes, it is outlined that teambuilding is formed by the previously gained knowledge of the individuals to collaboratively shape the team process with different views and approaches, which is defined as collaborative knowledge construction. The experiment shows that content-specific visualization increases individual knowledge structures in team processes (Fischer et al. 2002). These individual knowledge structures are directly linked to SMM. When it comes to virtual collaborative visualization, the external representation is formed via the support of ICT, which acts as a mediator between the human and the image (Walny et al. 2011).

However, there is no encompassing theory so far describing the effects of virtual collaborative visualization on teamwork (Liu et al. 2008).

7.4.2 Impact of Visualization on Digital Whiteboards

As Lurey and Raisinghani (2001) and Swaab et al. (2002) show, a continuing scientific investigation on appropriate tools to support virtual teams is needed. For example, Maynard and Gilson (2014) advocate that the development of innovative ICT for virtual teams would benefit from the investigation of SMM to involve individual adaptation capabilities.

We focus on visualization that mirrors thoughts and relationships and connections to understand a given content. One measure to visualize content in virtual teams are digital whiteboards (Maynard and Gilson 2014, Santos et al. 2015, Swaab et al. 2002, Tang et al. 2009). Digital whiteboards are digitized versions of a plain paper that can be used to sketch (complex) thoughts, relationships, and ideas to personally gain insights or to explain content to team members (Walny et al. 2011). Whiteboards – If physically or virtually present – differ from plain paper in terms of size to act upon (that influences the possibility to collaborate) or its means of change and modification through its ability to erase content (Ju et al. 2006). The possibility of changing and deleting content of visual representations that has been collected in teams offers the opportunity to find a common ground on specific content through agreements via collaborative visualization (Ju et al. 2006).

Past research has shown that the use of whiteboards supports thinking processes, but there is still a lack of research on specific thinking processes (Abowd and Mynatt 2000, Tang et al. 2009, Walny et al. 2011). Sketching (on whiteboards) is associated with flexibility and improvisation. Other than in text-based communication, e.g. via email that is rigid, collaborative visualization means moving images, text, data, thoughts, and ideas (Ju et al. 2006). Recent research additionally highlights the effectiveness of digital whiteboards to improve collective mindfulness and subsequently improve collective decision quality (Curtis et al. 2017). Collective mindfulness means that team members mutually contribute to the discussion, align their actions, and form a SMM (Weick and Roberts 1993). With the help of a digital whiteboard, participants were able to integrate new information from other team members better into their mental models and the overall communication patterns among the virtual team members were more effective (Curtis et al. 2017). This makes whiteboards an appropriate tool for the forming phase of a team process in order to create a common image that is a visual representation of collective understanding (Mynatt et al. 1999).

Analog whiteboards have restrictions in form of using markers, sticky notes, and photos (that need to be prepared in advance) on a dedicated surface (Mynatt et al. 1999). Work results on analog whiteboards are difficult to document (Mynatt et al. 1999). In contrast, digital whiteboards are more flexible and offer the opportunity to add information in form of photos, videos, audios, and text in real-time (depending on the functionality of the offered software). Due to the development of diverse digital whiteboards that can be used freely to some extent, digital visualizations of any content, either personal, individual, or team based have to overcome less barriers and can be used in diverse settings (Ju et al. 2006, Sorapure 2010). The original task of whiteboards has been transformed from sketching and drawing into visually expressing thoughts with diverse media opportunities on a screen (Ju et al. 2006). The opportunities that digital whiteboards offer for virtual collaborative visualization need further examination. Hence, we aim to analyze the chances of using digital whiteboards in the forming phase of virtual teams, which leads us to conduct an experiment in which we firstly define a contemporary, wicked problem for teams to test our artifact.

7.5 SMM in the Forming Phase of Virtual Team Performance

7.5.1 Shared Mental Models

Shared Mental Models (SMM) are dispersed systems, which unite knowledge structures to collaboratively agree upon individual representational conditions via delineated media (Banks and Millward 2000). SMM are measurable psychological constructs and describe the agglomeration of diverse mental models in a team (Mynatt et al. 1999, Rouse and Morris 1986). Each individual has an own mental model in order to incorporate the miscellaneous facets a person acts in. Mental models are individual cognitive displays, which directly interact with a person's environment and shape the reaction and interaction in any context (Resick et al. 2010, Rouse and Morris 1986). Mental models expose the necessities, wishes, and requirements of a person to generally interact in any situation and therefore shape decision making (de Vreede et al. 2012).

While mental models refer to an individual level, the construct of mental models is shifted toward a team level. Team Mental Models (TMM) mirror the interrelation of individual cognitive displays that fuse together in order to collaboratively care for occupational duties, such as task and performance of team interaction (Cannon-Bowers and Salas 2001, Resick et al. 2010, Rouse and Morris 1986). Within research on TMM, one area focuses on the similarity of mental models, which is called Shared Mental Models (SMM) (Bittner and Leimeister 2014, Cannon-Bowers et al. 1993, Cannon-Bowers and Salas 2001, Corvera Charaf et al. 2013, Mohammed et al. 2000, van der Pol et al. 2006).

The most common and general approach of SMM refers to a collaborative comprehension of every team member, although individual mental models vary (Klimoski and Mohammed 1994, Maynard and Gilson 2014, Santos et al. 2015). This indicates that SMM are an influencing factor for the success of team building and in general for the forming phase of team processes. Furthermore, SMM are measurable constructs that allow the assessment of team processes that are based on cognitive individual concerns, such as satisfaction, and therefore act as an indicator for successful collaboration (Klimoski and Mohammed 1994, Lim and Klein 2006).

SMM symbolize the individual structures of knowledge of one person to interact collaboratively with other knowledge structures, thus creating a joint course of action in relation to one's environment (de Vreede et al. 2012). These knowledge structures can be divided into two types: task-related and team-related (Johnson et al. 2007). Task-related SMM influence the team performance, as the team members' mental efforts can be allocated due to the reduction of communication demands (Langan-Fox et al. 2004). While prior research (Cannon-Bowers et al. 1993, Mathieu et al. 2000) focused on task-related structures, Johnson et al. (2007) developed a team-related measure, aiming to examine task-independent information about the team's interactions, attitudes, and skills. de Vreede et al. (2012) developed advanced categories of SMM knowledge structures, including the following team-related areas:

- knowledge structures on equipment and tools;
- knowledge structures on team task, goal, and performance requirements;
- knowledge about other team members' abilities, knowledge, and skills;
- knowledge about appropriate team interactions.

Past research often concentrated on one of these categories (de Vreede et al. 2012). We follow this approach and focus on the knowledge structure on team task, team goal, and performance requirements, since a common comprehension of all team members toward the task, goal, and procedure is the foundation of the forming phase of (virtual) teamwork (Mathieu et al. 2000). Therefore, we do not consider the area 'knowledge about other team members' abilities, knowledge and skills', as our focus lies on the comprehensive understanding of a wicked problem. Additionally, developing an understanding of each team member's abilities and skills requires more time and the entire process of problem definition and problem solving (Kanawattanachai and Yoo 2007). This involves the division of labor according to the individual knowledge and skills, which is why we focus on the problem definition phase.

7.5.2 Collaboratively Visualizing Wicked Problems and SMM

Sketching, as it is usually done on (analog) whiteboards, is a visual examination of relevant content of tasks, therefore acting as a means of communication for other task- and team-relevant people leading to sharing mental models, respectively 'shared visions' (Klimoski and Mohammed 1994, p. 7). Eventually, the ability of individual cognition in specific circumstances has positive effects when interacting in a team, which can be influenced by visualization (Liu et al. 2008). This initial situation directly leads, in terms of virtual teamwork, to the examination of the interaction among humans and computers and the analysis of specific virtual tools that are meant to support specific teamwork affordances (Liu et al. 2008).

Summing up, visualization has a positive effect on virtual team performance and consequently on the manifestation of SMM. Nonetheless, the question is whether SMM are able to support virtual teams while handling wicked problems, since the success of solving wicked problems is restricted by the boundaries of cognitive capabilities of individuals and teams (Buchanan 1992, Liu et al. 2008). Wicked problems challenge the human capacity, e.g. imagination (Liu et al. 2008). It is therefore necessary to develop appropriate tools to support teams - and in our case virtual teams - in the forming phase. Wicked problems are special cases, when it comes to the forming phase of teamwork, since an absolute understanding of every influence and dependency of a wicked problem is not achievable (Buchanan 1992).

The design process and the process of problem solving can be divided into two distinct phases. The first phase comprises the problem definition which 'is an analytic sequence in which the designer determines all of the elements of the problem and specifies all of the requirements that a successful design solution must have' (Buchanan 1992, p. 15). The second phase encompasses problem solving, where the requirements and elements are combined in order to create a solution. Wicked problems have no definitive formulation, which impedes the problem definition phase and leads to difficulties when determining all the elements on a team level. This means that the outcome of the problem definition phase cannot be assessed in order to evaluate whether a wicked problem was effectively defined. In this study, we focus on the forming phase of a team, where the task and the shared understanding of the task are in focus, which aligns with the problem definition phase.

Complex problems, that are easier to solve and have an overlap to wicked problems, have already been recognized in SMM research (Mathieu et al. 2000, Rouse et al. 1992). Complex Problem Solving (CPS) is a process that has been established within the scope of Psychology, where a sequence of tasks is needed to reach a proposed goal (Funke 2009). Challenges within CPS are complex, which indicate three requirements that influence clarification; connectivity, dynamics, and no-transparency. Connectivity refers to the interconnectivity of events and aspects, dynamics takes place through changing events and requirements, and no-transparency states that given events are not predictable (Funke 2009). CPS as defined by Funke (2009) inherits major aspects of the characteristics of wicked problems, which leads to the assumption that SMM also positively contribute to wicked problems (Thomas and Bostrom 2007). CPS has a positive effect on the forming of SMM, since the ability of adaptation is highly demanded in this context. Findings conclude that the forming phase of a problem-solving situation, the process, and the outcome can be improved by allowing people to visualize their thoughts (Blaser et al. 2000, Fischer et al. 2002). As visualizing a mental model can help when expressing complex thoughts (Fischer et al. 2002), one approach to support team-based solving of wicked problems is to achieve SMM by visualization.

7.6 Methodology

The presented theoretical backgrounds on teamwork and team stages, virtual teamwork, virtual visualization, whiteboards, and wicked problems in the context of SMM shape the foundation for our experiment on how to enhance and measure effectiveness in the forming phase of virtual teams. Our research objectives are to test, whether collaborative virtual visualization (on a digital whiteboard) of a wicked problem increases the effectiveness of the team forming phase.
In 2015, Santos et al. investigated the relationship between SMM and team effectiveness. Their model states that a high SMM lowers team conflicts, fosters creativity, and improves team performance. Next to creativity and team conflicts, their research model involves the testing of team effectiveness that is built on team performance and team satisfaction. We adapt their research model by measuring the shared understanding of team task and goal, team effectiveness and satisfaction. In order to analyze our propositions, we conduct an experiment and follow the approach of Dennis and Valacich (1999). The experiment requires the development of an artifact based on the above-mentioned findings (Hevner et al. 2004). In the next paragraphs, we provide a detailed derivation of our research propositions, followed by a description of our artifact, the conducted experiment, and its results.

7.6.1 Propositions

In contrast to MNT, we follow the assumptions of MST and MRT, which state that richer, personal media that supports the synchronicity of communication processes enhance interaction (Daft and Lengel 1986, Dennis et al. 2008, Dennis and Valacich 1999, Kock 2004). Therefore, we chose a digital whiteboard that supports collaborative and synchronous visualization of the team member's individual mental models. Enhanced interaction and communication thereby allow team members to allocate efforts on the task and share more information (Johnson et al. 2007). Team interaction, like communication and information sharing then leads to a higher SMM. In addition, as wicked problems have no exact definition, it is difficult to evaluate whether a team effectively defined the problem. Therefore, in order to evaluate whether a team went through a successful problem definition phase, other measures such as the SMM must be taken into account. In this regard, we derive proposition 1:

1. A collaborative virtual visualization tool supports the shared understanding of wicked problems.

According to Santos et al. (2015) a higher level of SMM leads to higher satisfaction of team members. In addition, Thomas and Bostrom (2007) and Swaab et al. (2002) state that properly designed tools lead to higher satisfaction in virtual teamwork. As a higher level of team satisfaction is strongly related to team performance (Costa 2003, Smith and Barclay 1997), we derive proposition 2:

2. A collaborative virtual visualization tool increases the level of satisfaction of the team members.

Staples et al. (2002) stated that perceived effectiveness is influenced by the use and functionality of information systems and Santos et al. (2015) reflects on the positive effect of the level of SMM and effectiveness in team performance. From these findings, we conceive proposition 3:

3. A collaborative virtual visualization tool results in a higher level of perceived effectiveness of the team members.

Because of the antecedents virtual teams are confronted with (Kirkman and Mathieu 2005), and the influence of the concept of visualization and its effects (Fischer et al. 2002, Liu et al. 2008, Ware 2012), we strive to further analyze how teams structured their teamwork. It is of particular interest, whether the use of a visualization tool leads to better structured interaction. Collaborative problem definition needs structured interaction, in order to reach effective interaction and build a shared understanding (van der Pol et al. 2006), which is why we derive proposition 4:

4. A collaborative virtual visualization tool leads to a better structured teamwork.

Through the key elements of SMM, i.e. knowledge structure of team task, goal, and performance requirements, we will be able to analyze meaningful criteria in order to answer our propositions and evaluate our artifact. The interplay and relation between our propositions are visualized in the following figure 18, which shows our derived conceptual research model.

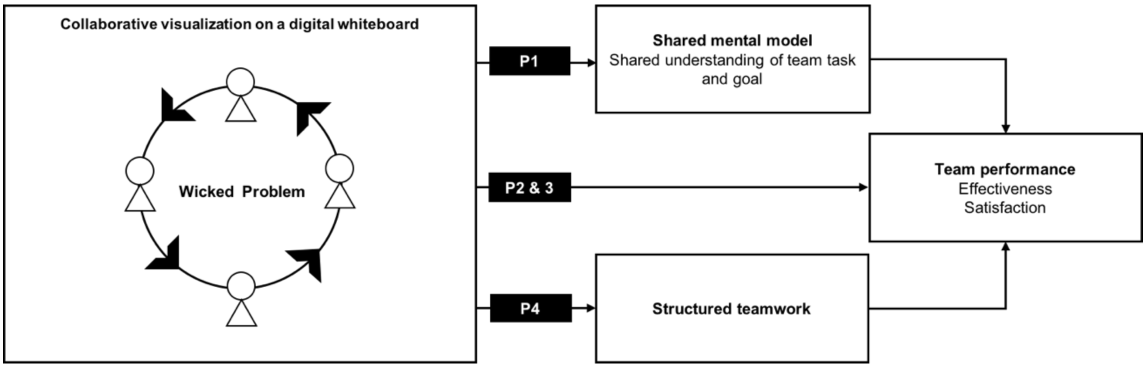

Figure 18 Paper 2 – Conceptual framework of our propositions

7.6.2 Artifact

Our prototype uses the digital whiteboard Spacedeck (Güther and Hartmann 2017). Spacedeck is a software that is based on the innovative Real Time Ideation System (RTIS), which allows users to collaboratively plan, perform, evaluate, and document creative and innovation processes. The digital whiteboard involves specific competencies like drawing freely, inserting text, forms, and multimedia such as audio-, video-, and image files. The whiteboard has an intuitive functionality and its collaboration can be performed in real-time with multiple geographically dispersed users and on different electronic devices. A chat function complements the visual communication. Although several more digital whiteboards are available, we have chosen Spacedeck as it enables direct user integration, which results in an advanced usability. Even though, other digital whiteboards offer more functionalities, such as templates, voting, and various export possibilities,

we have chosen Spacedeck precisely because of its intuitiveness. This makes it easy to use, clear, understandable, and similar to an analog whiteboard.
In addition, we provided visual material of a wicked problem on radioactive waste to the teams, at which we followed the subsequent characteristics of wicked problems (Buchanan 1992, Funke 2009):
Wicked problems have a high number of elements that are relevant to the solution process and are interconnected;

- Wicked problem solutions can be assessed as either good or bad, but there is no right or wrong;
- There is no similar course of action to the solution process;
- Wicked problems are connected to other (complex) problems and there is just one chance for success, and failure is no option.

The visual material of the wicked problem on radioactive waste for the whiteboard template contains 28 elements such as nuclear fission, uranium mining, tailing, nuclear medicine, nuclear reprocessing, and interim storage. The arrangement of the visual material on the template does not include a definite formulation or rules on stopping, and it is prepared to resemble a highly non-transparent structure with a variety of connections, influences, different possible goals, and confusing information (Buchanan 1992, Funke 2009). The radioactive waste visualization allows for changes and rearrangements to occur. An additional text explanation is included to provide every team with the same information on the task and the proceeding within the experiment. Additionally, we offer a real-time chat that serves as virtual communication medium.

7.6.3 Experiment Structure

Our experiment involved 40 students from undergraduate and graduate programs in the areas of Computer Science, Technology-oriented Business Administration, Engineering, and other technological studies. The age of the participants ranged from 22 to 30 years and the group consisted of 34 male and 6 female participants. All participants were recruited in the course of a lecture, however participation in the experiment was not mandatory. The participants took part in either the experimental group (EG) or control group (CG) and the distribution was blindly and randomly allocated. The distribution of the participants resulted in 10 teams. Consequently, our experiment included 5 experimental teams and 5 control teams with 4 members each. We limited the team size to 4 members since more team members tend to negatively influence the building of SMM (van den Bossche et al. 2010).
The experiment's preparations included the information of the group members concerning the tools to be used, since the participants should not be influenced by uncertainties of functionalities. The group work took place under real conditions, as all participants completed the experiment at home. The participants used their own devices and the communication was restricted to the tool. The experiment began by giving both groups the same written explanation of the wicked problem on radioactive waste, but the teams of the EG were invited to work collaboratively with the digital whiteboard (including a chat function), whereas the teams of the CG were invited to a chat conversation only. The instructions for both groups were identical. Both groups were asked to build a common understanding of the problem, find a common goal (not ideas), and reach a consensus. The teams had a limited time span of 20 minutes to fulfil their task.

After completion, all participants received a survey to evaluate the experiment's content. The survey contained questions that are directly linked to the level of SMM in respect to perceived effectiveness, satisfaction, and team performance/interaction.

7.6.4 Survey

To evaluate the experiment and to validate our propositions, we conducted a survey on the basis of previously defined constructs from past research (Alrushiedat and Olfman 2012, Cannon-Bowers and Salas 2001, Dennis et al. 1996, Johnson et al. 2007, Resick et al. 2010). The 40 participants were asked to rate their perception of the dependent measures ('shared understanding of team task and goals', 'satisfaction', 'perceived effectiveness', 'structured interaction') on a 5-point Likert-scale. The measures are constructed by firstly defining the measure 'shared understanding of team task and goals', which contains 21 items and is based on findings from Johnson et al. (2007) and Santos et al. (2015). Johnson et al. (2007) provide a comprehensive construct on how to measure 'sharedness' of team-related knowledge. The final construct contains 42 questions, which include five emergent factors of SMM, i.e. communication skills, attitude toward teammates and task, team dynamics and interactions as well as team resources and working environment (Johnson et al. 2007). As stated before, in our research we focus on shared understanding of team tasks and goals. Hence, we constructed the measure 'shared understanding of team task and goals' with 21 unweighted items based on items of Johnson et al. (2007) and Santos et al. (2015). As a second step, we determined the measure 'satisfaction' that evaluates the level of satisfaction of each participant concerning the collaborative visualization tool. This measure contains seven items grounded on Dennis et al. (1996) and Santos et al. (2015). Thirdly, we defined the measure 'perceived effectiveness' of the process, which contains four items based on Dennis et al. (1996), whereas the item ('How effective was this meeting compared to a face-to-face meeting.') is excluded from the statistical calculations due to its high deviation compared to the other items of the construct. The last measure 'structured interaction' indicates how well structured and goal oriented the discussion was and how the communication in the team was perceived. This last measure contains five items based on Alrushiedat and Olfman (2012) and van der Pol et al. (2006). The measure contains two questions, which are excluded from the statistical calculations and are independently treated. All other items used in the measures are weighted equally and are included in the statistical calculations. We calculated the internal consistency with Cronbach's alpha for each measure, to validate that all items measure the same concept (see tab. 1) (Cronbach 1951, Tavakol and Dennick 2011). The complete survey with the descriptive statistics can be found in Appendix 1.

7.6.5 Results

The results of the survey led to 1480 ratings from 40 participants. Table 1 shows the descriptive data of the research results and the Cronbach's alpha for each measure. Due to non-normally distributed data and the fact that Likert-scales were used (ordinal data), we calculated a set of Mann-Whitney U tests to validate our propositions (Gibbons and Chakraborti 2011, de Winter and Dodou 2010). The results with a significance level of 5% ($P = 0.05$) and r = Cohen's effect size are presented in table 3.

Measure	*Mean^{EG}*	*Mean^{CG}*	*SD^{EG}*	*SD^{CG}*	*α*
Shared understanding of the team task and goal	1.919	3.548	0.837	0.940	.966
Satisfaction	2.050	3.436	0.916	0.969	.899
Perceived effectiveness	2.233	3.700	0.698	0.788	.829
Structured interaction	1.917	3.183	0.743	0.983	.843

Table 3 Paper 2 – Descriptive data (EG: experimental group; CG: control group)

Measure	*U*	*r*	*Z*	*p*
Shared understanding of the team task and goal	*20708*	*0.662*	*-9.195*	*2.2e-16*
Satisfaction	*3173*	*0.408*	*-9.781*	*2.2e-16*
Perceived effectiveness	*348*	*0.465*	*-7.618*	*2.14e-15*
Structured interaction	*617*	*0.379*	*-6.207*	*1.05e-10*

Table 4 Paper 2 – Results of the Mann-Whitney U tests

The Mann-Whitey U tests indicate that each measure in the EG scored statistically significantly better than the CG (see table 4). In addition, the results of the survey outline that both groups perceived the discussion to be task oriented and not personal or criticizing (EG=1.450; CG=1.800), but also stated that many explanations were necessary during the process (EG=2.400; CG=2.250). However, the study results also show that the virtually supported forming phase was not perceived as effective as face-to-face meetings (EG=3.450; CG=4.000).

To deeper understand the relation between satisfaction, perceived effectiveness, and the shared understanding of team task and goals, we computed a Spearman's rank correlation analysis. We aimed to find out whether participants that experience higher effectiveness also experience higher shared understanding, and whether higher satisfaction also might lead to higher shared understanding within the group.

The computing of the relationship between satisfaction and shared understanding shows that there is a positive correlation between the two variables ($\rho = 0.830$, $p = 3.846e-11$). Overall, there is a strong, positive correlation between satisfaction and shared understanding. Participants who are more satisfied also valuate a higher shared understanding, while participants who are less satisfied valuate a lower shared understanding.

In addition, we computed the relationship between perceived effectiveness and shared understanding. There is again a strong, positive correlation between perceived effectiveness and shared understanding ($\rho = 0.823$, $p = 8.178e-11$). Participants that experience higher effectiveness also valuate higher shared understanding. Participants that experience a less effective group interaction also valuate a lower shared understanding. Figure 2 shows the scatter plots of both correlations and the division into the EG and CG.

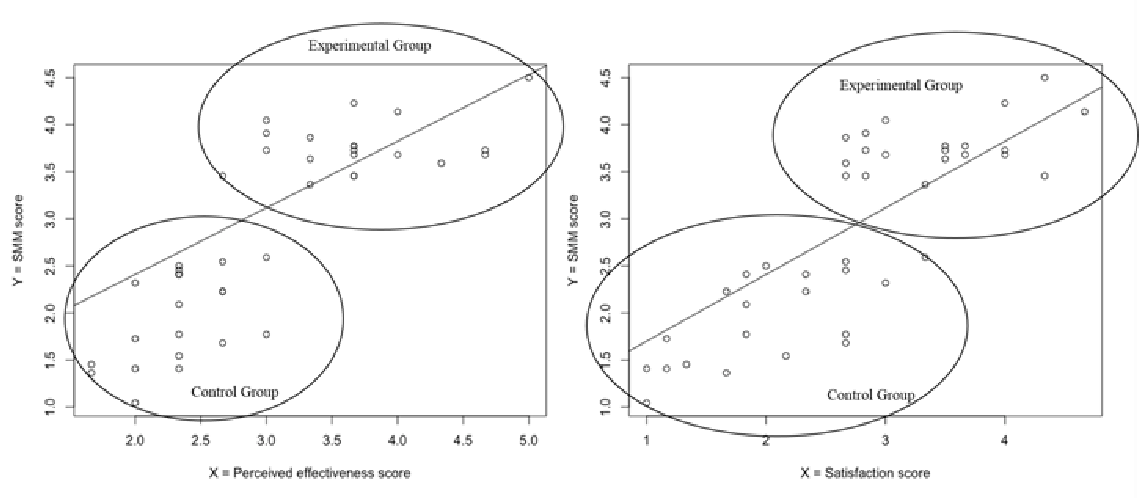

Figure 19 Paper 2 – Correlation between SMM and perceived effectiveness and SMM and satisfaction

Using figure 19, we derive that without visualization (CG) a limited degree of SMM, satisfaction, and perceived effectiveness is reached, which can be exceled by the support of visualization. Furthermore, the analysis of the chat discussions show that the experimental teams used on average 260 words for written communication in the chat. In contrast, the control teams used on average 514 words to communicate and fulfil their task. Eventually, all experimental teams came to a comprehensive visualization of the wicked problem of radioactive waste that contained every important element of the problem construct.

7.7 Discussion

Our research aims to develop an approach to enhance and measure the effectiveness of the forming phase of virtual teamwork. We tested the effects by implementing a well-designed prototype (reflecting SMM, particularly the knowledge structure team task, goal, and performance requirements) in an experiment, which follows the suggestion of Lurey and Raisinghani (2001). Furthermore, on the basis of prior research, we defined measures to test our propositions (Alrushiedat and Olfman 2012, Dennis et al. 1996, Johnson et al. 2007, van der Pol et al. 2006, Santos et al. 2015). First of all, we can state that our chosen measures serve the human-centered approach of evaluation. The results of the experiment, compared to our propositions, were based on a thorough literature review, which led to the following answers:

1. A collaborative virtual visualization tool supports a shared understanding of wicked problems: In summary, we can outline that in virtual teamwork SMM are formed by the support of visualization and the level of SMM is higher with visualization than without. This finding supports our proposition 1 and is in line with findings stating that appropriate ICT for specific environments influences the level of shared comprehension (Liu et al. 2008, Lurey and Raisinghani 2001, Maynard and Gilson 2014). The results of our experiment show that the EG had a significantly higher shared understanding of the team task and team goal, which indicates that the comprehension of even a wicked problem can be increased with the opportunity to visualize collaboratively in virtual teams. It furthermore outlines that specific virtual tools enhance the shared understanding of teams.

2. A collaborative virtual visualization tool increases the level of satisfaction of team members: The possibility to visualize collaboratively, although team members are geographically dispersed, results in a higher level of satisfaction compared to virtual team interaction without the possibility of visualization. This finding supports our proposition 2 and is in line with findings that underline the positive effect of visualization and perceived satisfaction in teams (Swaab et al. 2002).

3. A collaborative virtual visualization tool results in a higher level of perceived effectiveness of team members: The comparison of the two groups shows that the EG estimated their level of perceived effectiveness higher than the CG, which validates our proposition 3. This is in line with findings that highlight the effectiveness via visualization to build shared comprehension in team processes (Goldschmidt 2007). This indicates that an appropriate support for virtual teams to shape their team interaction, in our case visualization, positively contributes to individually perceived performance of the team (Maynard and Gilson 2014).

4. A collaborative virtual visualization tool leads to a better structured team performance: Since the EG evaluated the team interaction as well structured, our proposition 4 is also validated. This result is in line with findings that outline the positive effect on structured team performance through collaborative understanding (Lim and Klein 2006). Furthermore, the right support of ICT increases the level of structured team performance, opening the possibility to collaboratively visualize on a virtual level.

Our results support the findings from research on MRT (Daft and Lengel 1986) and MST (Dennis et al. 2008, Dennis and Valacich 1999) in stating that richer, personal media that allows for synchronicity within communication enhances the communication process. In contrast, our results do not provide definite evidence regarding the MNT. On the one hand, we were able to support the shared understanding, perceived effectiveness, and perceived satisfaction with the digital whiteboard. This is in contrast to the MNT, as our artifact can overcome cognitive obstacles that are formed via dispersed communication (Kock 2004). On the other hand, our experiment shows that the interaction within virtual teams is less effective than the interaction within face-to-face teams, as participants answered that the virtual collaboration was not perceived as effective compared to a face-to-face meeting. This is – according to findings from Warkentin et al. (1997) – due to the functionality and accustoming of team members toward the tool. This indicates that the functionalities of the virtual tool need to be further adapted and developed.
By choosing a team size of four participants, we followed the literature on teamwork stating that interaction is impaired in larger teams (Martins et al. 2004, Steiner 1972, Valacich et al. 1992). However, the interaction in larger virtual teams can be improved compared to analog groups, due to different communication mechanisms and functionalities (Gallupe et al. 1992, Link et al. 2015, Valacich et al. 1992). In contrast to that, the likelihood to reach a SMM decreases in larger teams, as more individual mental models need to merge into one SMM (Jeong and Chi 2007, Rentsch and Klimoski 2001). The measures we used in our experiment that examined the level of SMM were designed and evaluated with teams of 4-5 participants (Johnson et al. 2007, Santos et al. 2015). Further research is needed, to examine whether larger teams might also benefit from a digital whiteboard, as dividing and processing tasks between team members can reduce cognitive load (Kirschner et al. 2009, Link et al. 2015). Furthermore, the costs of recombining information afterwards are lower compared to the division of the information, especially in complex tasks (Kirschner et al. 2009). This trade-off between the positive and negative effects

should be measured in order to deeper understand if a digital whiteboard can even support the formation and shared understanding of larger virtual teams.

In accordance with past findings (Thomas and Bostrom 2007), the different usage of chat functions in the experimental and control group reveals that team communication has been adapted toward the possibilities of the offered virtual tool. Since our artifact provides the opportunity of visual communication, the need for written conversation was reduced toward technical support. The research from Curtis et al. (2017) aligns with our findings, as their results show that with the use of a digital whiteboard plus a chat function, a richer interaction and communication was reached compared to teams using solely a chat function. With the help of the digital whiteboard the teams mindfully shared information more effectively (leading to an increased collective mindfulness), instead of just holding multiple monologues. In our results, the chat histories of both groups show that the CG had limited conversations on the wicked problem's interconnections, influences, and structures. This highlights that the used ICT in virtual teamwork can have effects on the quality of interaction as predicted by Thomas and Bostrom (2007) and Curtis et al. (2017). According to the MRT, collaborative virtual visualization with a digital whiteboard can therefore be seen as richer media when compared to the sole use of a chat function when dealing with wicked problems.

The experiment shows that virtual collaborative visualization tools have positive effects on the level of SMM and therefore affect virtual team performance in presumably any phase of teamwork, if developed in an appropriate manner. To conclude, we can adhere that the level of SMM is evaluated higher when visualization supports virtual team interaction in the forming phase, which reiterates past findings (Curtis et al. 2017, Goldschmidt 2007). Hence, the results show that SMM act as a promising approach to measure virtual team interaction and evaluate virtual tools, which validates the findings from Thomas and Bostrom (2007) on the relation between SMM and collaboration technology. In summary, we can state that individual factors, such as satisfaction, play a major role in SMM in virtual team performance and in team effectiveness.

7.8 Conclusion and Outlook

Since ICT has an impact on the effectiveness of working in geographically dispersed teams, virtual tools for teamwork need to be developed further. The advantages of virtual teamwork require an appropriate embodiment of virtual functionalities that serve the chances as well as the challenges that come with virtual team interaction.

This paper started with the examination of (virtual) teams and phases of teamwork and moved on with a discussion on the means of visualization. We presented SMM as an indicator as well as a measurement for our artifact before presenting our experiment in detail. Our research results reveal that the usage of a digital whiteboard - with prearranged visual material on a wicked problem - positively affect team interaction, satisfaction, structure, and understanding, and consequently team performance. The evaluation of our artifact shows that visual communication in virtual teams positively influences the forming of team processes and tasks, which affects the team goal and performance requirements. We further found out that the application of the psychological construct of SMM led to a human-centered evaluation of a virtual tool. The findings of this paper shall initialize future analysis on various teamwork phases, as well as the development of virtual tools, which fit and improve the requirements of virtual teamwork and team members.

Our paper has limitations concerning the type of visualization accessible to virtual teams, which was concentrated on whiteboards, disregarding other collaborative virtual tools. Furthermore, the number of participants in the experiment was limited, as well as the level of the multidisciplinary approach of the participants. For future research, we suggest the examination of other knowledge structures of SMM in the context of virtual teamwork as well as the integration of other creative methods to enhance team performance. Additionally, the application of visualizations in other teamwork phases need further investigation as well as the influence of visual communication.

7.9 Acknowledgements

This paper is part of a project called DETHIS – Design Thinking for Industrial Services, funded by the German Federal Ministry of Education and Research (BMBF); Grant # 01FJ15100.

8 Paper 3

Digitization of the Design Thinking Process – Solving Problems with Geographically Dispersed Teams

Christoph Lattemann, Dominik Siemon, David Dorawa, Beke Redlich

Reprinted by permission from Springer Nature: Springer, Cham, Lecture Notes in Computer Science (Digitization of the Design Thinking Process Solving Problems with Geographically Dispersed Teams, Lattemann C., Siemon D., Dorawa D., Redlich B.), Springer International Publishing AG (2017), advance online publication, 05 03 2020 (https://doi.org/10.1007/978-3-319-58634-2_6. DUXU.)

8.1 Abstract

In a globalized world, collaboration within geographically dispersed team members is becoming more important due to the possibilities given by Information Systems (IS) and the increase in productivity of knowledge workers. Design Thinking (DT) is a creative innovation method that is originally performed to enable participants to collaborate successfully in analog workshops. By referring to this initial situation, we hypothesize that a virtual DT platform can be at least as effective for generating creative innovations as an analog one, if the platform and the underlying processes are designed in an adequate way that enables collaboration and communication.

The key question in this research is, consequently, how a virtual DT platform should be designed to enable effective real-time communication and collaboration like in regular face-to-face DT workshops.

As the guiding approach for our methodology, we apply a Design Science Research (DSR) approach. In the first section of this paper, we introduce the problem statement as well as a detailed motivation of our research project. Following, we present latest research on telework, virtual collaboration, and DT as the underlying foundation for our propositions. In section three, we introduce our methodological research approach, introducing our artifact – a virtual DT platform – and finally presenting our case study and survey results. Subsequently, we discuss the findings vis-à-vis recent research findings and draw conclusions. We can reveal that our virtual DT platform is applicable for virtual collaboration and team members can produce a valuable, creative and innovative solution in less time than working face-to-face.

8.2 Introduction

Due to the continuous development of IS, digitization is shifting the workforce toward an economy that generates value through digital work (Keuper et al. 2013). Furthermore, Information and Communication Technologies (ICT) enable remote work. Research show that remote work increases knowledge workers' work-life balance and productivity, saves time on commuting to work, decreases pollution, and attracts qualified workers across the world (Sandmann 2000, Vilhelmson and Thulin 2016). The primary reason why knowledge workers support remote work is based on the empirically proven fact that it increases productivity, job satisfaction, employee's time flexibility, and lower expenses (Sandmann 2000).

In a globalized world, ICT supports work environments for remote work of geographically dispersed teams, which is becoming more important (Daniels et al. 2001). To cope with contemporary requirements for collaboration, ICT tools, which support virtual teamwork are becoming a necessity for companies (Bailey and Kurland 2002, Butler et al. 2007, Gibson and Gibbs 2006, Raffaele and Connell 2016). Research shows that remote work performs over regular office work, when there is a need for uninterrupted concentration on one task (Vilhelmson and Thulin 2016).

de Vreede and Briggs (2005) state that collaborative processes must be strictly designed, so that teams can achieve a common goal. Hence, remote teams need structured collaborative processes in order to develop an innovative solution for the customer relating to the common goal that needs to be achieved (de Vreede and Briggs 2005). DT is one strictly designed, user-centered, creative, and collaborative innovation method that has proven to be successful during analog face-to-face co-work settings (Brown 2009, Kolko 2015). A user-centered innovation collaborative method, such as DT, lowers the risks of creating unwanted results and consequently, risks concerning the implementation of innovations are reduced (Müller and Thoring 2012).

To guarantee that a DT team performs well, specially trained moderators/coaches must set up, organize, and guide the team in a sound way (Brown 2009, Lattemann and Fritz 2014). However, coaching and moderating in a virtual environment is much more complex than in a face-to-face environment, and it requires adequately designed supporting ICT tools (platform) and functionalities (Unger and Witte 2007). In this paper, we propose that virtually performed DT can, despite the difficulties that come with virtual collaboration, be as effective as DT performed in an analog environment, if adequately designed supporting ICT tools are used. In order to test this proposition, we develop and test the effectiveness of a virtual DT platform.

As the underlying approach for our paper, we follow the principles of DSR (Gregor and Hevner 2013) by structuring our research accordingly: introduction, literature review, method, artifact description, evaluation, discussion, and conclusions. DSR has proven its applicability in IS and guarantees a general approach to develop and evaluate artifacts (Peffers et al. 2007). Consequently, the introduction is followed by the review of relevant research in related fields, which are in this case telework, virtual collaboration, and DT. The research streams and their findings serve as a foundation for the development of the artifact and formulation of propositions. The section is followed by the presentation and explanation of our methodological approach. Following the seven guidelines of DSR, we introduce and evaluate our artifact – a virtual DT platform. The evaluation is based on a case study and a survey.

8.3 Related Work

In order to build an appropriate artifact and to define the propositions of our research project, related work is reviewed. To gain insights, we present and discuss research findings on remote work/telework, virtual collaboration, and DT. These three perspectives will be discussed separately and fuse in our research framework.

8.3.1 Remote Work/Telework

Harker Martin and MacDonnell (2012, p. 603) define telework as the 'substitution of communication technology for work-related travel […it…] can include work from home, a satellite office, a telework center or any other work station outside of the main office […]'.

Due to the advancements of ICT, people can work from a distance and still be within the structure of an organizational framework of a company (Harpaz 2002). Harpaz (2002, p. 75) states that a ''telecommuter' can structure his/her work tasks and working life in many ways – dependent on the nature of the work, the organization, the customer-base, etc.'. The difference between 'telecommuters' is a variable degree of 'remoteness' – 'the ratio of time spent on organizational premises versus the time spent at home' (Harpaz 2002, p. 75). Remote work and telework are interchangeable terms which appoint to employees, who work from a distance, while being connected via ICT within the organizational framework of a company (Harpaz 2002, Sandmann 2000, Townsend et al. 1998).

One of teleworks primary advantages is the potential increase in productivity which can range from 10% to 40% on average (Sandmann 2000). The main reason for an increase in productivity is that teleworkers can choose their working hours flexibly without any disturbances from colleagues and time lost for travel (Harpaz 2002, Sandmann 2000). But telework comes also with disadvantages, such as no separation between home and work, a need for self-discipline or the over-availability syndrome (Harpaz 2002). Apart from the high increase in productivity, an organization faces also some risks when letting employees' telework such as a possible loss of commitment, investment in training, and new supervising methods (Harpaz 2002). Harpaz (2002) concludes that advantages of telework outweigh the disadvantages. Furthermore, not only single teleworkers, but virtual teams, composed of teleworkers, can outperform normal (non-virtual) teams (Townsend et al. 1998).

8.3.2 Virtual Collaboration

Collaboration is considered when at least two or more people are working on the same problem to achieve a shared goal (Martinez-Moyano 2006). According to Nunamaker and Briggs (2015), collaboration encourages to be more creative and therefore innovative solutions can be presented. In the past, collaboration has been geographically determined to one physical place. With recent technological advancements, it has been possible to collaborate remotely and simultaneously (Nunamaker and Briggs 2015, Redlich et al. 2017).

The fast paced business environment needs individuals who are able to generate innovative ideas in order for companies to remain competitive on the global market (Massetti 1996). One way to enhance the generation of creative ideas, is the implementation of ICT that fosters idea generation within a company (Massetti 1996). During a controlled experiment, Massetti (1996) has found out that ICT enhance the creative performance of individuals, while generating more novel ideas than with a pen and paper. Teams connected virtually together via ICT are called 'virtual teams' and the process is called 'virtual teaming' (Bergiel et al. 2008). Virtual teams, who are focusing on the customer's needs while generating great solutions in the today's competitive economy, have high chances of succeeding (Bergiel et al. 2008).

Voigt and Bergener (2013) argue that the majority of creative work is done in teams, rather than by individuals. Companies are understanding creativity as a competitive advantage and strategic asset and that is why they often choose to apply ICT to enhance creative collaboration (Briggs et al. 2003, DeFillippi et al. 2007). From an IS perspective, a focus is set toward designing systems which are supporting teams at developing creative ideas (Voigt and Bergener 2013). In order to create such a system that focuses on the development of creative ideas, de Vreede and Briggs (2005) state that collaborative processes must be strictly designed, so that teams understand each phase of the collaborative process and can achieve a common goal. Such a collaborative and strictly designed innovation process can be referred to as DT (Brown 2009).

8.3.3 Design Thinking – A Method for Innovation Management

DT is a creative and user-centered innovation method to solve complex/wicked problems within multidisciplinary teams (Brown 2008, Buchanan 1992, Johansson-Sköldberg et al. 2013). Due to the fact that DT is a human/user-centered problem solving approach, empathy is the foundation since it reveals the core needs and real problem statements (Bellet and Maloney 1991, Brown 2008). During the entire DT process, a focus is set toward the user's needs, starting with understanding and observing the problem and the user, redefining the problem statement from a user perspective, continuing with the generation of ideas and ending with the creation of a product, service or process that is tested (Buchanan 1992). For each phase there exist multiple methods and tools that can be applied to enhance the creation of new ideas, understand the problem or prototype (Keuper et al. 2013). Additionally, the DT approach inherits a mindset, which acts as a framework of requirements to secure the quality of a DT process (Lawrence et al. 2010, Lindberg et al. 2012). The DT mindset involves aspects such as user-centeredness, creativity, iteration, multidisciplinarity, creativity, co-creation, and space aspects (Both 2009, Brown 2008, 2009, Grots and Pratschke 2009, Seidel and Fixson 2013, Taura et al. 2012). Especially, while performing DT workshops, the design of the space and surroundings, such as moveable furniture, tools and materials, visualization of new ideas foster creativity (Grots and Pratschke 2009).

Design Thinking Process and Process Features. Due to its popularity, we have chosen to focus on the DT process approach based on Stanford's d.school, which includes the phases 'empathize', 'define', 'ideate', 'prototype', and 'test' (d.school Stanford 2009). During the first phase 'empathize', it is important to observe the behavior of users and gain empathy for their problem by communicating with them. This phase helps understanding the potential users, for whom teams are developing a new product, service, or processes (d.school Stanford 2009). After collecting a wide spectrum of insights and needs from potential users, information must be focused to formulate a clear problem statement during the second phase 'define'. Hence, a clear definition of the problem serves as a guideline for the multidisciplinary DT team to generate creative ideas from the user's perspective. The key process features of the third phase 'ideate' are to generate a wide spectrum of diverse and creative ideas without boundaries and judgement by other team members at the beginning and to focus on a few ideas at the end of the idea generation process (d.school Stanford 2009). During the fourth phase 'prototype', the development of a prototype begins that allows interaction, because during the last phase 'test' new insights may be gathered by observing the user's interaction with a prototype. After testing the prototype, the multidisciplinary team(s) may realize that the problem has not been defined correctly or the prototype needs an improvement and the phases can be repeated due to DT's iterative process.

During 'empathize', 'define', 'ideate', and 'test' communication within the team and with the users is very important to gain empathy, understand the problem, and communicate while discussing ideas. This interactive communication is considered as an important feature of DT (Brereton and McGarry 2000). While generating ideas, the DT team needs to organize, share and develop their ideas, hence, collaboration and creativity are key features in this phase. During the development of prototypes interaction among the team members is needed (Brown 2009). In

summary, four key features of DT can be extracted as relevant for our research: communication, developing creativity, collaboration, and interaction. These four key features must be supported by a Virtual Design Thinking (VDT) platform. While designing an artifact for the VDT platform, two perspectives need to be considered – management and technology (Hevner et al. 2004).
The discussion on remote work/telework, virtual collaboration, and DT indicates that wicked problems can be effectively solved by virtual teams, who collaborate on a VDT platform. This finding guides us to our research questions: Can a VDT platform outperform face-to-face DT? What is an adequate design of a VDT platform to effectively support virtual DT teams?

8.3.4 Propositions in Regard to a Virtual Design Thinking Platform

In this section, propositions are derived from the presented findings.
In a globalized and highly competitive economy, companies need creative individuals and teams to remain or grow the company's market share with the creation of demanded goods (Massetti 1996). The modern workforce prefers telework when a task demands a high level of concentration (Vilhelmson and Thulin 2016). To achieve a common goal, a virtual team needs a structured collaborative process (de Vreede and Briggs 2005). To further guarantee a high level of competitiveness, company's innovations (product, service, process) must be user-centered and of high relevance (Cronin and Taylor 1992, Massetti 1996). Cronin and Tayler (1992) state that the quality of a good is measured in relation to consumer satisfaction. DT is a user/customer-centered approach that focuses on the development of innovative and desired goods by the customer (Müller and Thoring 2012). We therefore derive the following proposition:

1. *A VDT platform supports dispersed and remote teams at achieving satisfactory innovations for their customer.*

ICT allows people to work remotely on projects (Harpaz 2002). Guthrie (2001) states that high-involvement work practices increase job satisfaction and also productivity. People who work remotely have the chance of improving their time management skills and be more productive (Harpaz 2002). Sandmann (2000) confirms the increase of productivity in telework and states that an increase in productivity between 10% and 40% on average can be expected, when people are working remotely. Individual teleworkers can be connected via ICT to form a virtual team (Townsend et al. 1998). Due to an increased level of productivity and structured collaboration via ICT using DT a shared goal can be faced (Brown 2009, Kolko 2015). Based on these findings, we derive the following proposition:

2. *A VDT platform increases a remote team's productivity/efficiency at innovating.*

In the remainder of this paper, we will test these propositions.

8.4 Methodology

As the guiding approach for our methodology, we apply DSR (Hevner et al. 2004). DSR has proven its applicability in IS and provides a structured approach to develop and evaluate artifacts (Peffers et al. 2007). Our methodological approach is based on the seven guidelines of DSR (Hevner et al. 2004), shown table 5.

Guideline	Description
Guideline 1: Design as an artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective Design Science Research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design Science Research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Research Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design Science Research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Table 5 Paper 3 – Design Science Research guideline by Hevner et al. (2004, p.83)

Following the seven guidelines, we introduce and evaluate our artifact – a VDT platform. The evaluation is based on a case study and a survey. Because there is limited research on the digitization of a DT process, we chose an exploratory case study to test and improve our artifact. A case study is suitable, when the aim of a contribution is to answer 'how' and 'why' questions and if the behavior of the involved participants cannot be manipulated (Baxter and Jack 2008). The developed artifact is tested under controlled quasi-real conditions with a geographically dispersed team. The principle research rigor of DSR (guideline 5) is to determine how well an artifact works or does not work, in order to enable the development of new artifacts study (Hevner et al. 2004). The explanatory case study is focused to answer the questions of how well our artifact works (Baxter and Jack 2008).

The designed artifact in this contribution (guideline 1) can be considered an instantiation, 'type of system solution', which can demonstrate the feasibility of a VDT platform (Hevner et al. 2004, p. 77). We have analyzed the process features of each DT phase in respect to communication, development of creativity, collaboration, and interaction and derived the required features for an adequately designed VDT platform. We did not develop new ICT tools but we assembled suitable existing ICT tools for virtual communication, collaboration, creative work, and interaction into the VDT platform based on Voigt's and Bergener's framework (2013). A detailed description of the VDT platform instantiation is presented in the next subsection.

Guideline 2 of DSR refers to the relevance of the problem, which can be solved with a technology-based approach as described in the introduction of this paper (Hevner et al. 2004). We evaluated our artifact (guideline 3) by conducting an explanatory case study under quasi-real conditions (see subsection 8.4.2) (Hevner et al. 2004). Additionally, we performed a survey to compare the findings from the case study with the participant's opinion about various factors, such as the quality of the result, pace of work, quality of communication, required skills to participate or the efficiency of virtual collaboration.

The contribution of our research (guideline 4) is to show that geographically dispersed teams can innovate as effectively as face-to-face teams, by using a VDT platform (Hevner et al. 2004). Our case study will answer how a VDT platform should be designed to enable effective real-time communication, collaboration, creative work, and interaction like in regular face-to-face DT workshops. The findings are presented in this section.

Guideline 6 of the DSR framework states, that not all means (infrastructures), ends (utility and constraints), and laws (cost and benefit constants) can be considered while designing an artifact since it is infeasible, but it should be focused on the utilization of available means, ends, and laws (Hevner et al. 2004). That is the reason why we assemble already existing, easy accessible (internet) and free-of charge ICT tools, in order to design the artifact of the VDT platform. While designing the artifact of the VDT platform both perspectives have been considered – management and technology (guideline 7) (Hevner et al. 2004).

In the following subsection, we present and explain our artifact for a VDT platform.

8.4.1 Virtual Design Thinking Platform

Guideline 1 (design as an artifact) of DSR requires the instantiation of a viable artifact. Voigt and Bergener (2013) identified a framework for the development of systems for creative group processes. We have chosen Voigt's and Bergener's framework because a creative group process is inherent in DT and the framework stresses the importance of communication, group collaboration, and to develop new services or products (prototypes). Voigt and Bergener (2013) also argue that teams are more creative than individuals. In order to enhance creativity, IS are often applied (Briggs et al. 2003). Furthermore, virtual teams can outperform offline teams (Townsend et al. 1998). Our VDT artifact is focusing on enabling the development of any type of innovation, such as service, product or process, while the geographically dispersed team members are collaborating on an ICT platform. Further, our VDT artifact combines various access-free internet communication, collaboration, and interaction tools, which foster creativity. The requirements for our ICT tools have been derived from the four key process features of DT: communication, creative work, collaboration, and interaction. The artifact of our VDT platform and its supporting ICT tools for each DT phase is shown in figure 20.

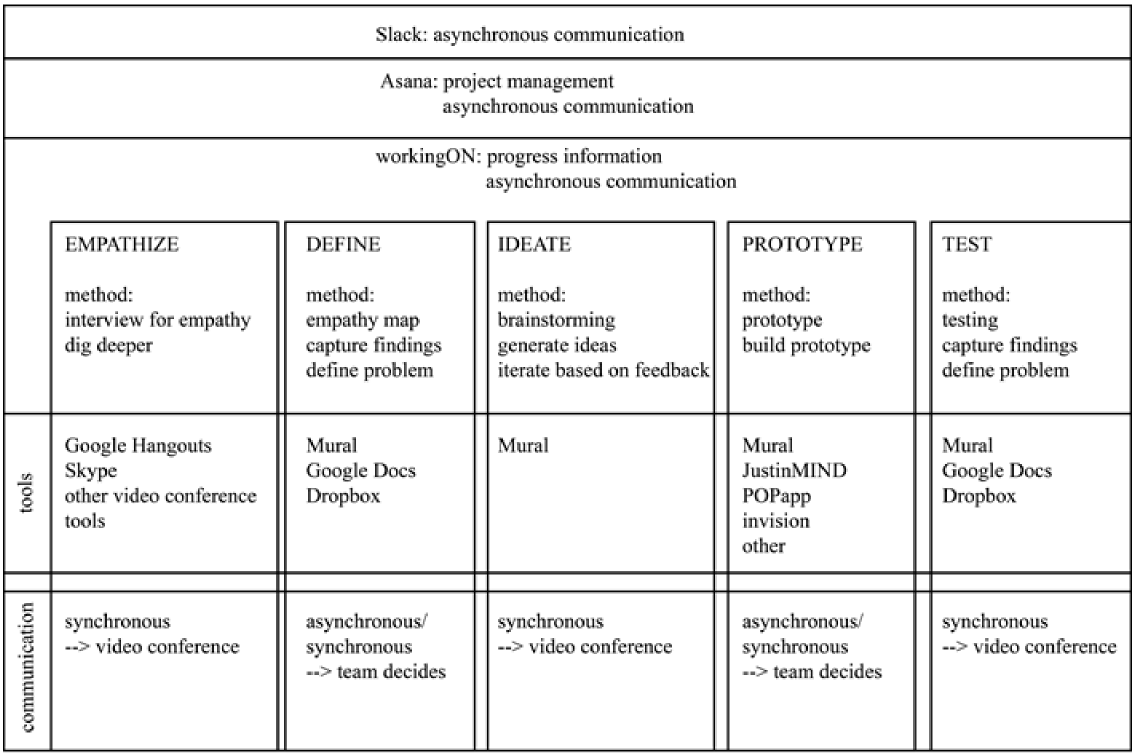

Figure 20 Paper 3 – Our Virtual Design Thinking platform artifact

Communication is an important key feature of the whole DT process. Virtual teams can apply synchronous (real-time) and asynchronous (no real-time) communication (Mabrito 2006, Schoberth and Schrott 2001). Virtual synchronous communication can be conducted by using for example video conferencing (Berge 1999).

According to guideline 6 of DSR, the artifact should be focused on the utilization of available means (infrastructures), ends (utility and constraints), and laws (cost and benefit constants) (Hevner et al. 2004). This is why we assemble existing free to use ICT tools for our VDT platform. In the following, the applied ICT tools, which were applied in all DT phases, will be described.

We identified three ICT based communication and collaboration tools, which are used throughout all five DT phases. We suggested Slack (2017) as a tool for all asynchronous communication in the group, e.g. for tracking project updates. Slack has been chosen because it is a free-to-use software, and it is a widely-known tool for text-based synchronous and asynchronous communication. We introduced Asana (2017) as a project management tool for remote teams. It has been chosen because it makes teams more efficient, makes team's goals clear, and reduces communication efforts. The platform workingON (2017) enables a minimalistic status reporting on each task. It has been chosen because of its easy-to-use functionality and usability (status reporting), which is needed for structured teamwork. In the following, we will describe ICT tools, which are applicable in each individual DT phase.

Tools for the 'empathize' phase. In the emphasize phase, team members have to get familiar with the problem at hand, immerse in the life of others and build up empathy with users (user-centered approach). To do so, synchronous communication is necessary. Documentaries in form of written text, photos, and videos need to be developed, shared and explained within the team. In our case study, the groups were free to choose their preferred tool for their synchronous communication. However, we proposed video conferencing tools for communication such as Google Hangouts (2017) and Skype (2017).

Tools for the 'define' phase. In the define phase, an asynchronous and synchronous communication is necessary since teams may decide to discuss their observation together or write down their comprehension of the problem individually. Suggested ICT tools that support participants to share their written information are the following ones: Mural (for sharing unstructured information, such as pictures or audio files), Google Docs (for written text documentations), and Dropbox (for sharing files). Mural is a digital whiteboard (Suarez-Battan 2012). Google docs can be used to virtually collaborate simultaneously or asynchronously (Dekeyser and Watson 2008, Google Docs 2017). Dropbox (2017) enables file sharing. These ICT tools have been suggested to be used, because they offer simultaneous and asynchronous collaboration, are easy-to-use, are widespread, and are (in their basic versions) free of charge.

Tools for the 'ideate' phase. The ideation phase is a highly interactive and creative phase. Within this phase ideas are collaboratively developed. Mural enables virtual collaborative and creative work. This virtual whiteboard is free-of-charge and can be used in an intuitively way. Google hangout was suggested for synchronous communication (Berge 1999).

Tools for the 'prototype' phase. The characteristics of the given problem and of the possible innovations (product, service, process) define the prototyping phase and the applied methods. The methods, which can be applied in this phase range from rapid prototyping, over website mock ups to virtual role plays (just to name a few). For the development of apps and website mock ups, we suggested to use Justinmind, POP app or InVision app (Justinmind 2017, Marvel 2017, zendesk 2017). For visual 3D-prototypes the groups were free to use any suitable computer aided design software, which suits best their needs and experiences.

Tools for the 'test' phase. The goal of the test phase is to present and review the prototype. In principle, user insights are recorded (video, photo, text) and shared. We suggested to use the same ICT tools for asynchronous communication as in the emphasize phase, i.e. Google Hangout were suggested to be applied.

8.4.2 Design Evaluation: Case Study

By following the DSR methodology, we evaluated our proposed artifact within an exploratory case study under quasi-real conditions (Hevner et al. 2004). We constructed a survey to capture the group member's perceived effectiveness of our artifact (Fink 2002). A total of seven people have participated in the case study, which consisted of six male design team participants and one male assignment provider (acts as the customer). All design team participants are between 23 and 26 years old. The assignment provider is 45 years old. The design team participants' backgrounds are in Computer Science, Crash Simulation Engineering, Patent Law, Production System Engineering, Business Administration, and Mechanical Engineering. The assignment provider is a professor of Aeronautical Engineering. The case study has been limited to three days and all participants have been located at different places across Germany.

Case study structure. We recorded an instructional video where we explained the work team DT and the purpose of this study, in order to minimize the need for moderation and coaching in the DT process. In the beginning of the case study, the team members needed to watch the instructional video and the group was introduced to the initial assignment (problem to be solved). The task of the DT team was to come up with an innovative idea on how to advertise a specific communication platform used by the International Forum for Aviation Research (IFAR) to the IFAR employees and external project partners. The NASA and the German National Aeronautics and

Space Research Center (DLR) use the social network platform, called IFARLink, to connect scientists and executives and discuss upcoming topics in aviation.

During the 'empathy' phase, the assignment provider introduced the task to and discussed the task with the team. In the 'define' phase, the team members individually formulated their understanding of the assignment before they collaboratively discussed their understandings by using video conferencing. In the 'ideation' phase, the team used the virtual whiteboard Mural to conduct brainstorming, and to cluster and to select ideas.

As the final idea, the team agreed on the development of an infomercial video to introduce and advertise the IFARlink platform to the end-users. In the 'test' phase, the script for the video was shown to the assignment provider (customer) via internet (available at https://www.ifarlink.aero/video) and discussed by the support of video conferencing to iterate the solution. Finally, the infomercial video was presented the board members of IFAR.

After the completion of this case study, each team member had to fill out a questionnaire with 38 items. The assignment provider/customer received a specific questionnaire to gather information about his prominent role during the DT process.

The next section covers the design of the two questionnaires.

8.4.3 Questionnaire and Data Analysis

For each of the five phases of the DT process, questions were derived based on the guidelines by Porst (2000) and Fink (2002) to determine if the VDT platform (our artifact) supported creative teamwork (communication, collaboration, interaction). Before the virtual teamwork started, two control questions were asked about the team members' preferred way of communication, collaboration, and interaction in group work. Further, this question helped to determine if the experiences with the VDT platform changed group members' opinions about their preferred way of communicating, collaborating, and interacting in teamwork.

The questionnaire was divided into six sections. Section 1 listed items about the perceived quality of the result of the VDT. Section 2 of the questionnaire had questions about the required skills to use the VDT platform and to communicate, collaborate, and interact in a creative way via ICT. The questions in section 3 asked about participants' perceived effectiveness of the virtual collaboration. The fourth sections contained questions about the workflow and continuity. Section 5 contained items to get information about group members' perceived level of satisfaction of the results and quality of the outcome. Section 6 listed question about the perceived quality of the communication within the team.

We furthermore asked about the group members' experiences with the suggested ICT tools, with the applicability, the usefulness, and the degree if support for creative work in each single phase of the DT process. To do so, we referred to questions from the Creativity Support Index (CSI) (Cherry and Latulipe 2014). The CSI covers six dimensions 'Enjoyment, Exploration, Expressiveness, Immersion, Results Worth Effort and Collaboration' with two questions each (Cherry and Latulipe 2014, p. 21).

As the 'assignment provider' was not directly involved in group work but in communication and coordination task, we established another questionnaire to get information about the assignment providers' experiences with digital collaboration, and experienced difficulties. To get information about these experiences, qualitative, open-ended questions were asked (Appleton 1995).

8.4.4 Data Analysis and Results

We conducted a three-staged analysis method to gather qualitative data, including data reduction, data display, and conclusion drawing (Appleton 1995). In order to achieve a data reduction, we abstracted and transformed the answers into insights based on the answers from the group members. The answers were clustered on a whiteboard, patterns were analyzed, and conclusions were derived in a narrative approach.

Face-to-face or virtual collaboration. Four team members preferred direct, non-ICT based collaboration, two participants expressed their perception that 'offline' collaboration leads to better collaboration. Two group members were indifferent in their opinion about the effectiveness of offline and ICT-based group work. One person answered that the process itself is very structured and motivates people to collaborate and only focuses on the problem to find a good solution.

Necessity of Skills. The participants have been asked about the skills that are necessary to complete the DT process. According to the answers, basic computer skills are necessary to be able to set up all ICT tools and to be able to perform virtual teamwork. Two out of six group members think that for VDT communication is as important as a creative and structured thinking.

Efficiency of virtual collaboration. Four out of six participants answered that results are not achieved in a faster way in a face-to-face environment (in comparison to a virtual setting). The results show that ICT tools foster creativity, which leads to a faster solving of a given problem and the sharing of information is faster in a virtual environment. However, two out of six group members think that results could be achieved faster in a face-to-face setting due to less technical issues and non-verbal communication.

Quality of the results. All six group members expressed that the VDT platform leads to better results (in comparison to face-to-face settings), although the expressed reasons for this vary.

Quality of communication. Conference calls are perceived by three out of six group members' as good as face-to-face communication, as there was 'no noticeable difference in workflow' and that everybody was able to see each other. The other three group members missed non-verbal communication and mentioned slow internet bandwidth as a limiting factor for virtual communication.

Workflow and continuity. Four group members mentioned that catching up with the group progress has not been a problem because everybody was able to see what other participants did in the meantime, due to asynchronous communication.

Empathize phase. All of the participants answered that they would not understand the problem better while being in person. The group members stated that they were able to ask questions in the same manner and with the same effectiveness as in face-to-face meetings.

Define Phase. The participants stated that they did not experience any difficulties in defining the problem and collectively formulating the problem digitally. One participant stated that there is less pressure to understand everything related to the problem, because ICT tools and ICT-based methods help to understand the details. In general, all team members appreciated how well the problem was defined in the virtual, remotely conducted 'define' phase.

Ideate phase. The following table 6 presents the results of the CSI analysis with the software Mural. The results show that the digital whiteboard Mural succeeded at enhancing creativity according to the CSI by Cherry and Latulipe (2014) as all CSI scores are way above 50%. Digital whiteboards, such as Mural, support idea generation and support creativity in the process. Nevertheless, two team members mentioned that they had problems with organizing their ideas.

Six Dimensions of Creativity Support	Results
Exploration	86.66%
Enjoyment	83.93%
Expressiveness	73.85%
Immersion	80.18%
Results Wirth Effort	91.02%
Collaboration	89.28%

Table 6 Paper 3 – CSI Results for Mural (CST) based on Cherry and Latulipe (2014)

Prototyping phase. The team decided to continue to work with Mural in the prototyping phase to write a script for the informational video (prototype). Five team members mentioned that they were not able to prototype the idea in any better way in person, because the tool provided a good overview of the process and the progress.

Test phase. All participants mentioned in the questionnaire that gathering feedback in person would not lead to any better results than with the digital-based solution. Furthermore, the team members were very satisfied with the test phase, because they had a common understanding of the solution.

Data analysis of assignment provider. The assignment provider (customer) stated that he prefers to use a virtual communication and collaborate platforms for group work, since it offers him the freedom of location choice. He experienced no quality loss in any regards.

8.5 Discussion

Our research aims to find out how effective a VDT platform can perform in comparison to face-to-face DT. In this paper, we firstly introduced our motivation, problem statement, and methodology. We structured this paper along the logic of DSR and, therefore, started with an examination of related research that builds the theoretical foundation for a) our artifact/VDT platform and b) the derivation of propositions, which allow to answer our research question (Guthrie 2001, Hevner et al. 2004, Sandmann 2000, de Vreede and Briggs 2005). Within section 8.4, we introduced our methodological approach based on the seven DSR guidelines and started with the introduction of our artifact, continued by the presentation of our evaluation approach, a case study and a survey (Gregor and Hevner 2013). Within this section, we fuse the findings from the related work. Our research results prove proposition 1, i.e. a VDT platform supports remote teams at achieving satisfactory results for their customer.

Our artifact is a digital representation of the creative innovation method DT. DT follows a structured logic of five iterative phases. Design Thinker's values are driven by a specific open, collaborative, and creative mindset for group work. This is in line with De Vreede and Briggs (2005), who state that virtual teams are in need for a structured, collaborative process to achieve a common goal.

The results of the case study and the survey, with particular regard to the stated satisfaction of the assignment provider (Cronin and Taylor 1992), prove that the VDT platform supports remote teams at achieving satisfactory results for their customer (which is in our case the assignment provider). Therefore, our proposition 1 is supported.

Proposition 2 – A VDT platform increases a remote team's productivity/efficiency at reaching goals.

The VDT platform supports remote-based DT by providing adequate ICT tools. Due to the results from our case study and survey, the participants using the VDT platform confirm that their perceived level of efficiency in virtual collaboration was higher in comparison to face-to-face interaction. The answers of the survey reveal that the VDT platform supports a more structured collaboration that leads to reaching goals more efficiently, which is in line with de Vreede and Briggs (2005). This is also in line with recent findings that remote work/telework leads to a higher productivity/efficiency of reaching goals in general (Harpaz 2002, Sandmann 2000). Additionally, the evaluation revealed that team members focus more on the task when using the VDT platform, which affects the efficiency of collaboration. This can be traced back to a 'high-involvement work practice', which – according to Guthrie (2001) – increases productivity and efficiency. Hence, our proposition 2 is supported.
However, our findings also show that the majority of participants prefer face-to-face collaboration instead of virtual collaboration, which is due to a lack of non-verbal communication and technical issues that interrupted the workflow.
To summarize, we can state that our artifact – the VDT platform – is a viable solution to effectively do DT in a virtual way. Nonetheless, there is room for improvement concerning the satisfaction of virtual team performance and overcoming technical difficulties.

8.6 Concluding Remarks and Outlook

Through the continuous process of digitization and development of IS, work is increasingly performed virtually (Keuper et al. 2013). The use of IS in companies allows individuals and teams to perform remote work/telework and thereby create values. This, on the one hand, leads to more flexibility in time management and productivity of workers but, on the other hand, requires adequate ICT to allow and support virtual collaboration (Sandmann 2000, Vilhelmson and Thulin 2016, de Vreede and Briggs 2005). The need for ICT supported collaboration for remote work of geographically dispersed teams is gaining importance and companies are challenged to keep up pace with this contemporary necessity (Daniels et al. 2001). Furthermore, companies require innovative products, services, and/or processes to satisfy customer's needs and to achieve success (Bergiel et al. 2008, Massetti 1996). DT is a creative innovation method that is originally used in analog team settings to develop innovative products, services, and/or processes (Brown 2009, Kolko 2015, Müller and Thoring 2012). The DT process, DT methods, and DT mindset together form a strictly designed procedure that is targeted toward user-centered innovations. To meet contemporary business requirements, our research project aimed at enabling virtual teams to perform DT in a geographically dispersed setting with the support of a newly designed VDT platform. We set up an artifact that follows the requirements of DT with the support of existing platforms and tools. In this research paper, we present our research of the evaluation of our artifact, which is based on the research question: How effective can a VDT platform perform compared to face-to-face DT?

In this paper, we firstly introduced our motivation, problem statement, and methodology. We structured this paper based on DSR, and therefore, started with an examination of related work that builds the theoretical foundation for a) our artifact/VDT platform and b) the definition of propositions that enable the answering of our research question. Within section 3, we introduced our methodological approach based on the seven DSR principles and started with the introduction of our artifact, continued by the presentation of our evaluation approach, a case study and a survey (Hevner et al. 2004). Our propositions – a VDT platform supports remote teams at achieving satisfactory result for their customer and a VDT platform increases a remote team's productivity/efficiency at reaching goals (Harpaz 2002, Sandmann 2000) – are confirmed based on the examination of related research work and our findings from the evaluation. Nonetheless, our evaluation revealed that a lack of non-verbal communication and challenges with technical issues downgrades the performance of our VDT platform in comparison to face-to-face interaction.

Concluding, we can reveal that DT can be virtually performed without any loss of efficacy in comparison to face-to-face DT. Nevertheless, there is room for improvement of the VDT platform. A fully automated platform would probably lead to positive effects on the workflow and the effectiveness of virtual DT collaboration. Hence, further research is needed.

Our paper has several limitations that need to be considered for future research. The digitization of DT entails the adherence of all DT requirements. For upcoming research, the effectiveness of the VDT platform also needs to be evaluated concerning the level of (team) creativity within the process and of the solution itself. Furthermore, there are several approaches for DT phase sequences, which can be tested. The number of participants within the case study is restricted, additionally future research could be conducted to test how the virtual DT process works with participants from different backgrounds, different levels of computer skills, more multidisciplinary, multicultural, diverse gender settings, and different ages in the team constellation. Additionally, the influence of altered timeframes for DT performance could be tested as well as potential differences when developing products, services or processes.

8.7 Acknowledgement

This paper is part of a project called DETHIS – Design Thinking for Industrial Services, funded by the German Federal Ministry of Education and Research (BMBF); Grant # 02K14A140.

9 Paper 4

Towards Semi-Virtual Design Thinking – Creativity in Dispersed Multicultural and Multidisciplinary Innovation Project Teams

Beke Redlich, David Dorawa, Dominik Siemon, Christoph Lattemann

This paper by the above-mentioned authors was published in the Proceedings of the 51st Hawaii International Conference on System Sciences (HICSS) 2018 and can be found here: https://aisel.aisnet.org/hicss-51/cl/virtual_teams/5/.

9.1 Abstract

This paper aims at examining whether the innovation approach Design Thinking (DT), which is usually performed in an analog setting, can also be performed in a semi-virtual setting. We conducted an experiment comparing a fully analog to a semi-virtual DT workshop with overall 59 participants from 27 different countries and 11 different disciplines separated into an experimental- and control group. For the evaluation, we composed items from the psychological construct of Shared Mental Models (SMM) and discussed existing media theories in order to draw conclusions on the impact of performing DT semi-virtually in regard to using a digital whiteboard. Against our expectations and assumptions from theory, we reveal that a semi-virtual DT workshop can lead to high levels of shared understanding, satisfaction, and perceived effectiveness. We argue that the applied digital whiteboard supports a creative semi-virtual collaboration due to its advanced functionalities, which supports the Media Richness Theory.

9.2 Introduction

Since the ongoing advancement of Information and Communication Technology (ICT), communication and collaboration holds new opportunities for teams to communicate and collaborate time- and/or location independent for different business purposes. A need for face-to-face collaboration becomes less necessary as audio and video-chat, shared documents, and other collaborative applications support the constantly rising number of virtual teams (Gilson et al. 2015). Furthermore, the increasing competition pressures companies to continuously innovate to find creative solutions (Amabile 1988). Therefore, team creativity in virtual collaboration becomes an important issue for practice to perform and for science to investigate (Martins and Shalley 2011).

Past research focused either on cultural aspects or on psychological issues and competencies of team members, which was followed by examinations on teams and tasks (Gilson et al. 2015). More recent research emphasizes the need to analyze explicit innovation projects in virtual teams instead of testing certain tools (Ebrahim 2015).

This paper aims at examining whether the innovation approach Design Thinking (DT), which is usually performed in an analog setting, can also be performed in a semi-virtual setting. DT is an approach that is inherently based on teamwork, creativity, collaboration, and multidisciplinarity with the objective of developing innovative products, services or processes. The overall approach consists of three dimensions concerning the DT process, DT methods, and the DT mindset that shapes the interaction (Carlgren, Rauth, et al. 2016, Lindberg et al. 2012).

Our paper incorporates research from various scientific fields on understanding virtual team performance. We particularly focus on the performance of creative and innovative virtual team. Therefore, we conducted an experiment that compared a completely analog DT workshop with a semi-virtual DT workshop. 59 students from 27 different countries and 11 different undergraduate programs participated in this study. For the evaluation, we referred to items from the psychological construct of Shared Mental Models (SMM), in order to examine the level of shared understanding of team task and goal, satisfaction, and perceived effectiveness (Dennis et al. 2008, Johnson et al. 2007, Santos et al. 2015, de Vreede et al. 2012). Our research presented in this paper deals with the underlying question whether if and how a semi-virtual DT workshop impacts team interaction in terms of the above-mentioned items.

Additionally, we evaluated the participants' application of a provided ICT-based tool and its functionalities – a digital whiteboard with task-specific functionalities – to get a deeper understanding of what an appropriate ICT tool in our context needs to offer.

In the following section, we will briefly present and discuss the major theoretical implications on creativity and virtual teams, DT and innovation as well as SMM. Additionally, we present a discussion on existing media theories as the underlying foundation for further discussions on technology fit. In section 3, we derive propositions from theory, we introduce the design of the experiment, the participants and procedures, measures as well as our results. Section 4 discusses our findings vis-á-vis the media theories. In the closing section, we conclude and provide suggestions for future research.

9.3 Semi-Virtual Design Thinking

Our overall intention to facilitating DT semi-virtually is motivated by several major aspects. Therefore, we firstly discuss the underlying principles of DT. Further, we present past research on the link between creativity and (semi-)virtual teamwork. Afterwards, we introduce the psychological construct of SMM and relate this to DT and virtual teams. In the closing part of this section, we introduce a debate on media theories.

9.3.1 Creativity, Innovation, and Design Thinking

Since on the one hand, dispersed workplaces and advanced ICT increase the existence of virtual collaboration, and on the other hand, a rising pressure for creative and innovative solution development is putting pressure on companies, there is a need to transform suitable approaches that successfully enable both aspects. DT is one approach for innovative collaboration that made his way successfully in the business world (Dunne and Martin 2006, Efeoğlu et al. 2013). DT can be labeled as a systematic approach that fuses multidisciplinary problem solving strategies in a sequence of phases that are shaped with various methods (Carlgren, Rauth, et al. 2016, Lande et al. 2012, Stickdorn and Schneider 2012).

In summary, DT consists of a DT process, DT methods, and a DT mindset. The DT process is an iterative model that is based on phases: a phase for understanding and observing to build empathy, a phase for defining a point of view that radically changes the perspective to user's needs, an ideation-, prototyping-, and a testing phase. The order of the phases guarantees to apply different problem solving techniques originating from Social Science, Design Science, and Engineering. This leads to the inclusion of deductive, inductive, and abductive reasoning, which encourages the development of (radical) innovations (Lande et al. 2012).

DT methods are - to a large extend - existing methodological approaches, borrowed from different disciplines, which are individually compiled due to the initial (design) challenge and team competencies. Examples are stakeholder analysis, journey maps, persona, prototyping, etc. (Efeoğlu et al. 2013, Goodwin 2011, IDEO.ORG 2018d).

The DT process and methods are embedded in a DT mindset. The DT mindset frames the team interaction such as staying open-minded, leaving hierarchical orders, thinking outside the box, and being creative as well as fostering multicultural- and multidisciplinary team arrangements (Carlgren, Rauth, et al. 2016, Rauth et al. 2010). A skilled DT coach guarantees that the DT mindset as well as the DT process and DT methods are applied during teamwork.

DT is originally performed in analog settings and its approach concerning phases, methods, and mindset has proven to be successful for contemporary challenges companies have to face. We follow Rive and Karmoker (2016), who argue that an ICT-supported DT approach can also tackle contemporary business problems concerning dispersed collaboration and innovation pressure.

As business routines and challenges oftentimes result in a combination of face-to-face and virtual meetings during projects due to restrictions of resources (i.e. time and money), we decided to analyze the performance of a semi-virtual DT approach.

In principle, there are two approaches to design the environment for a semi-virtual DT. The technology-based approach is to examine existing or develop new ICT tools and test if they fit for DT (Wenzel et al. 2016). The human-centered approach firstly analyzes the socio-psychological aspects of collaborative and creative teamwork and secondly to determine the underlying technology. We agree with Gilson et al. (2015) in arguing that diversity and creativity in virtual team interaction need more examination. Hence, in our research, we follow the socio-psychological approach.

9.3.2 Creativity in (Semi-) Virtual Teams

When it comes to performing semi-virtual DT, past research concerning creativity aspects in virtual teamwork can be used as guidelines for our examination.

Virtual teams are constantly defined as being impacted by two major dimensions, which are geographical dispersion and technologically mediated communication (Gilson et al. 2015, Webster and Wong 2008). In general, this leads to less boundaries and an increase in location-independent collaboration, which is mediated via ICT (Gilson et al. 2015, Myers and Sadaghiani 2010). We focus on semi-virtual teamwork as a combination of face-to-face meetings as well as virtual collaboration. Past research shows that different types of virtual teams, such as semi-virtual teams, need further examination due to their specific needs and functioning (Gilson et al.

2015, Webster and Wong 2008). This is why this paper examines in particular semi-virtual DT. A pivotal element of DT is the creativity of the teams and their dynamic in the DT process.

Comparable to our research and experiment, past examinations argue that virtual teams are often used when it comes to specific projects (Gilson et al. 2015). Nonetheless, an appropriate examination with semi-virtual teams in specific projects, such as creative innovation projects are still missing.

Nevertheless, the aspect of creativity in virtual teams is already examined to a certain extent. Creativity can be defined as '(…) the production of novel, potentially useful ideas about work products, practices, services, or procedures' (Amabile et al. 1996, Martins and Shalley 2011, p. 539, Shalley 1995). Creative teamwork is fostered by the integration of diverse opinions, viewpoints, and experiences, etc., which can be supported by geographically-dispersed and diverse team members that contribute to one task (Hargadon and Bechky 2006, Martins and Shalley 2011, Milliken et al. 2003, Taggar 2002, Woodman et al. 1993). Hence, the opportunity of virtual collaboration via ICT can positively contribute to creativity in teams (Gilson et al. 2015, Mathieu et al. 2008). In contrast, vam Knippenberg and Schippers (2007) found that virtual collaboration for a shorter time frame might negatively contribute to the creative performance of a team (vam Knippenberg and Schippers 2007, Martins and Shalley 2011). Mediating factors are the cultural diversity in the team and the number of members, as both factors negatively influence the complexity of collaboration (Martins and Shalley 2011, Zhang et al. 2007).

Based on these past findings, we argue that semi-virtual teamwork in a short-time innovation project based on DT has a high level of creativity.

9.3.3 Measuring Semi-Virtual DT with SMM

In order to evaluate our semi-virtual DT approach, we use the psychological construct of SMM. SMM are the accumulation of several mental models in a team (Cannon-Bowers et al. 1993, Cannon-Bowers and Salas 2001, Rouse and Morris 1986). Mental models are the internal representation of external impressions that an individual is exposed to and which determine the way someone acts and reacts in situations (Rouse and Morris 1986). When it comes to teamwork, each team member has an own mental model and over the period of interaction an alignment of several mental models leads to SMM (Mathieu et al. 2000).

SMM are an indicator for successful teamwork and the evaluation of the measureable construct can state the level of shared understanding (Klimoski and Mohammed 1994, Lim and Klein 2006). Past research shows that especially in diverse team constellations the level of shared understanding is an important indicator for success (Bittner and Leimeister 2014). Furthermore, past research has shown that a high level of SMM positively contributes to team creativity in short-term collaborations, which hence leads to successful teamwork (Redlich et al. 2017, Santos et al. 2015).

de Vreede et al. (2012) defined four categories of SMM knowledge structures. Past research often focused on one of four structures, which we follow (de Vreede et al. 2012). We, therefore, chose the knowledge structure 'team task, goal, and performance requirements' (de Vreede et al. 2012). Particularly this SMM reflects the object of our research, because it elucidates team interaction in a specific short-term project and it refers to the successful accomplishment of a solution for a given problem. Exactly this is what DT is about. We measure 'performance requirements' by asking team members about their 'satisfaction' and their 'perceived effectiveness' of the group work.

9.3.4 Media Theories for ICT Evaluation

In this section, we will discuss media theories, which pinpoint effects on performance of workgroups applying ICT for collaboration.
There are three media theories that are considered important for our research: The Media Naturalness Theory (MNT), the Media Synchronicity Theory (MST), and the Media Richness Theory (MRT) (Daft and Lengel 1986, Dennis et al. 2008, Dennis and Valacich 1999, Kock 2004).
MNT expands on the idea of human evolution and argues that the usage of ICT suppresses major elements of face-to-face communication, which leads to perceptive barriers (Kock 2004). This argumentation does not take into account that current ICT open the opportunity for multichannel communication with diverse opportunities such as synchronous, audio-, and visual communication (Schouten et al. 2016).
In contrast to MNT, MST argues that communication can even be improved when a given ICT allows for the appropriate speed of synchronicity that a process of communication requires (Dennis et al. 2008, Dennis and Valacich 1999). Furthermore, MRT posits that the level of appropriate functionality, which an ICT inherits, influences the effectiveness of the usage. The richer a medium for communication, the more effective it is (Daft and Lengel 1986).
The examination of our semi-virtual DT approach in regard to media theories shall give a ground for discussion on the fit of our chosen technology and, therefore, create an understanding which functionalities of our chosen ICT – a digital whiteboard – were used during application (Gilson et al. 2015, Martins and Shalley 2011). Furthermore, past research shows that multiculturalism in virtual teams has distinct negative effects on the process, and moreover affects the level of creativity (Martins and Shalley 2011). In contrast, other studies show consistent levels of creativity in virtual, multicultural teamwork irrespective to the choice of ICT (Gilson et al. 2015). Nonetheless, an advanced examination for specific ICT that supports the usage in particular creative settings are missing (Gilson et al. 2015).

9.4 Propositions

The presented theoretical discussion shows the relevance and necessity of a deeper examination of semi-virtual teamwork in general, and on creative teamwork (DT) in particular.
We aim at examining whether semi-virtually performed DT is as successful as analog-performed DT. Successfulness in this context relates to the level of SMM, which shall indicate whether team members evaluate their team performance positively in respect to the applied knowledge structure. In this paper, we test whether the usage of a given virtual tool – a digital whiteboard with specific functionalities – works as appropriate alternative compared to collaboration on an analog whiteboard with multiple functionalities, which foster creativity in a DT workshop. Our major research questions (RQ) are:

(1) How is the level of SMM in a DT workshop impacted when teamwork is performed in a semi-virtual setting?
(2) Is a digital whiteboard an appropriate tool to support semi-virtual DT workshops?
(3) Which functionalities of a digital whiteboard are needed to appropriately support the development of SMM in a semi-virtual DT Workshop?

To answer the above-mentioned research questions one and two, we evaluate the influences of the level of shared understanding, satisfaction, and perceived effectiveness based on the psychological construct of SMM, specifically the knowledge structure 'team task, team goal, and performance requirements' in a semi-virtual DT setting compared to an analog DT setting. We propose that a semi-virtually performed DT workshop with the support of a digital whiteboard…

1. …leads to a low shared understanding of teams compared to an analog setting.
2. …leads to a low level of satisfaction for team members in comparison to an analog setting.
3. …is perceived with low effectiveness compared to an analog setting.

These propositions are based on findings concerning MNT, which argues that the usage of ICT hinders certain cognitive processes and, therefore, is not as effective as an analog collaboration (Kock 2004). Since SMM are an indicator for shared cognitive representations to perform team interaction, we propose that the level of shared understanding, satisfaction, and perceived effectiveness is low in comparison to an analog performance (Maynard and Gilson 2014, de Vreede et al. 2012). The term 'low' indicates a rating of less than neutral in a 5-point Likert-scale. Complementary, to draw further conclusions for our research question two and give answer to three, we evaluate whether the usage of a digital whiteboard with its diverse functionalities supports a semi-virtual DT workshop appropriately. This is reached via an additional survey for the experimental group on the preferred use of functionalities within the given tool. Additionally, this will be related to the above-presented media theories to draw further conclusions.

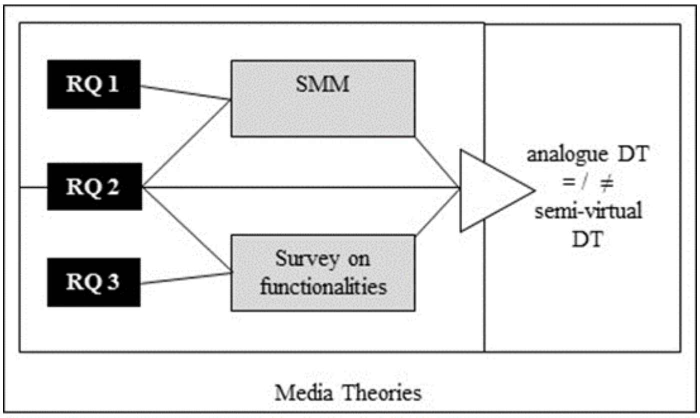

Figure 21 Paper 4 – Evaluation design

9.5 Design

For the purpose of the experiment, we developed one DT workshop concept that follows the requirements of defining a phase sequence and methods from different disciplines and were, hence, applied for the experimental- and control group. Each workshop was stretched over three days and included the phases understand, observe, point of view, ideate, prototype, and test. In-between the predefined timeslots for performing the phases there was time left for potential iteration of the team process. For each phase at least two methods were used to shape the process. The following methods were used in the specific phases:

Understand: The teams were asked to brainstorm and use the method 'Define your Audience', a visual method that asks the team members to identify all stakeholders that are relevant for the design challenge (IDEO.ORG 2018b). Additionally, the needs of the stakeholders are outlined.

Observe: The method 'Interview for Empathy' was conducted in order to build up empathy with stakeholders while asking specifically designed questions (Both 2009). Based on the findings from the interviews, a 'Journey Map' for a sample of stakeholders was created by the team members to generate insights (IDEO.ORG 2018d).

Point of View: In this phase a bundle of 'Persona' were developed, which are fictional characters based on the insights from observation (Goodwin 2011). Afterwards, the method 'Create Insight Statement' was used for each Persona, which in turn leads to the adjustment of the initial design challenge from a user-centered perspective (IDEO.ORG 2018a).

Ideate: For the ideation phase 'Brainstorming' was used to generate ideas. Based on this, the method 'Gut Check' was applied to arrange and expand idea bundles (IDEO.ORG 2018c).

Prototype: The team members were free to choose from either material prototypes, roleplay, storyboard or IT prototypes such as mock-ups.

Test: The developed prototypes were tested in a World Café, where stakeholders and experts were able to give feedback on the solution. Afterwards, the prototypes were improved by the team members based on the feedback from others.

The DT workshop took place in a dedicated DT lab, which is flooded with natural light, where all furniture and equipment is moveable, and colorful consumables are provided.
The semi-virtual setting refers to the realization of specific phases in a location-independent manner. The phases 'Understand' and 'Ideate' were executed location-independent with all team members of one team. This procedure is supported by Baskerville and Nandhakumar (2007) who argue that communication and collaboration are attached to team members and not to places (Gilson et al. 2015). The instructions of how to use particular methods were given in advance in a face-to-face setting before team members spread out. All team members used a given digital whiteboard and were free to use additional ICT for communication, such as skype, WhatsApp, FaceTime or iMessage. The decision which ICT to use, was left to each team since it opens the opportunity that teams apply their existing ICT and do not need to get used to two new applications. This procedure is supported by past research, which argues that participants shall feel comfortable with technology usage in order to support interaction (Martins and Shalley 2011).

9.5.1 A Digital Whiteboard for Semi-Virtual DT

For the purpose of performing a semi-virtual DT workshop an appropriate software needs to be applied. In a common analog DT setting, whiteboards are the preferred medium for collaboration. Whiteboards allow for a collaborative visualization of content to collectively create insights (Walny et al. 2011). Furthermore, the opportunity for changing and erasing visual content supports the building of common visual representations, which fosters the level of SMM (Ju et al. 2006, Redlich et al. 2017). We, therefore, apply a digital whiteboard for the objective of performing a semi-virtual DT workshop.
There are several digital whiteboards available. We chose to use 'Mural.co' (Suarez-Battan 2012). Mural.co is a web-based software that allows for real-time collaboration, communication, and visualization with multiple users. Mural.co has an intuitive usability and integrates various

functionalities that an analog whiteboard offers as well. Collaborative visualization in this software includes the functionalities of using post- it notes, forms-, shapes-, connections-, text-, and photo insertion as well as using predefined templates such as a Business Model Canvas. Communication is additionally supported with a real-time chat. Furthermore, Mural.co offers the functionality for collaborative voting on content and tracking of single activities in a protocol to allow for traceability of single actions (Suarez-Battan 2012).
The combination of functionalities as well as an easy subscription process, convinced us to use Mural.co as support for the semi-virtual DT workshop.

9.5.2 Participants and Procedures

Our experiment involved overall 59 students from diverse undergraduate programs such as Economics, Management, Industrial Engineering, Computer Science, Social Sciences, Intelligent Mobile Systems, Electrical & Computer Engineering, Politics & History, Physics, Biochemistry & Cell Biology, and Medicinal Chemistry & Chemical Biology. The age of the participants ranged from 19 to 22 years and the group consisted of 36 male and 23 female participants. The participants were born in 27 different countries throughout the world. The experiment was executed within an extracurricular professionalization offer but the participation in the experiment was mandatory. The experiment lasted 6 days – three days for the control group (CG) and three days for the experimental group (EG). The allocation to either the CG or the EG was coordinated via an official and automated extracurricular activity registration tool with no possibility for manipulating the groups. The group sizes varied due to automated registration and institutional conditions, which led to a group size of NCG=24 for the control group (analog workshop) and NEG=35 for the experimental group (semi-virtual workshop). The distribution of the participants resulted in six teams for either CG or EG. The team size varied between four to six team members each.
Prior to the beginning of the experiment, all participants took part in a one-day session on the introduction to DT, where the theory and ideas of DT were explained and a one-hour design challenge was performed. Furthermore, the teams prepared their own design challenges as the starting point for the three-day workshops, which were accompanied by dedicated DT coaches.

9.5.3 Measures

In order to test our propositions, we conducted a survey based on previously defined concepts (Dennis et al. 1996, Johnson et al. 2007, Santos et al. 2015). After each DT workshop the participants of the EG and CG filled out the digital form individually and were invited to rate their perception on the dependent measures shared understanding, satisfaction, and perceived effectiveness on a 5-point Likert-scale. We defined the measures in the following way:
The measure 'shared understanding of team task, goals' is based on findings from Johnson et al. (2007) and Santos et al. (2015) and is sampled as a plausible construct for the measurement of team-related acquaintance. This measure includes 15 items on shared understanding of team task and goal related perception, communication, and team climate.
The measure 'satisfaction' contains six items based on findings from Dennis et al. (1996) and Santos et al. (2015). This measure evaluates the individual level of every participant's perception according to satisfaction with the performance of a semi-virtual DT approach.

The measure 'perceived effectiveness' includes three items based on findings from Dennis et al. (1996). These items evaluate the perceived effectiveness concerning the focus on problem-solving, input of individual skills, and task structuring.

The survey contains 24 questions. All items used in the measures are weighted equally and included in the statistical calculations. We calculated the internal consistency with Cronbach's Alpha (α) for each measure, to validate that all items measure the same concept (Table 1) (Cronbach 1951, Tavakol and Dennick 2011). Due to the use of Likert-scales, we measured Mann-Whitney U (U) tests to validate whether there is a significant difference in the results of the EG and the CG. Based on this, we computed the Spearman correlation for every measure. Furthermore, we asked the participants of the EG which functionalities they used while using the digital whiteboard. Multiple answers were possible in a selection of the following functionalities: post-it notes, text insertion, photo insertion, voting system, predefined templates, chat function, shapes and connections, and icons. Furthermore, the participants had the choice of typing in feedback what they liked and what they disliked about using Mural.co (Suarez-Battan 2012).

9.5.4 Results

Based on the answers from the survey, we calculated α, which validates that all items measure the same concept. Table 7 shows the results of the survey in comparison of the CG and EG, inclusive standard deviations (SD), and α.

Measure	*$Mean^{CG}$*	*$Mean^{EG}$*	*SD^{CG}*	*SD^{EG}*	*α*
Shared understanding	4.583	4.337	.617	.680	.923
Satisfaction	4.542	4.400	.629	.658	.848
Perceived effectiveness	4.417	4.280	.735	.719	.564

Table 7 Paper 4 – Descriptive data

The results show that the EG evaluated the team interaction concerning shared understanding, satisfaction, and perceived effectiveness slightly lower in comparison to the CG. The results show an insignificant difference of both groups.

Because of the existence of non-normal distributed data and the usage of Likert-scales within the survey, we additionally calculated U (Table 8). Due to the comparably small number of participants in the experiment and the insignificant results, we additionally computed effect size with Cohen's d (d).

Measure	*U*	*d*	*Z*	*p*
Shared understanding	275.5	0.379	2.491	.025
Satisfaction	328.5	0.219	1.428	.153
Perceived effectiveness	350.5	0.188	1.095	.273

Table 8 Paper 4 – Mann-Whitney U tests

The results of the U tests validate that there is no significant difference between the EG and the CG. To further draw conclusions on the insignificant results, we computed a Spearman correlation (ρ) (Table 9).

Measure	ρ	p
Shared understanding and satisfaction	0.773	7.561e-13
Shared understanding and perceived effectiveness	0.747	1.038e-11
Perceived effectiveness and satisfaction	0.691	1.434e-09

Table 9 Paper 4 – Spearman Correlation

The Spearman correlation coefficient ρ measures the monotonic relationship of two variables and the results show that the correlation of the measures perceived effectiveness and satisfaction represent a moderate uphill positive relationship (ρ=.691). The correlation of the measure satisfaction and shared understanding (ρ=.773) as well as shared understanding and perceived effectiveness (ρ=.747) represent a strong uphill positive linear relationship.
Additionally, we asked the participants of the EG questions on the usage of Mural.co. Every participant strongly agreed that Mural.co is an appropriate whiteboard for location-independent teamwork.

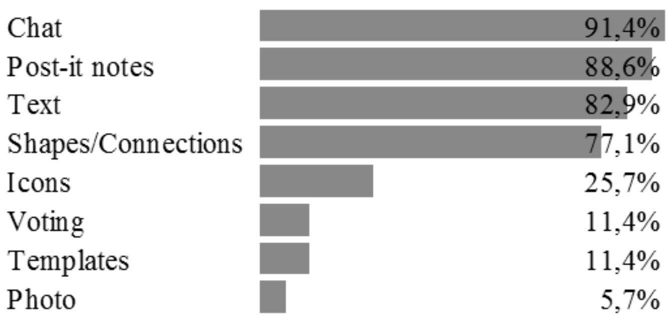

Figure 22 Paper 4 – Use of single functionalities

Concerning the use of specific functionalities when using Mural.co, the participants of the EG stated that the chat, post-it notes, text insertion, and shapes and connections were frequently used (Figure 22). In contrast, the functionalities of inserting icons, using the voting system, predefined templates, and photo insertion were less frequently or rarely used.

9.6 Discussion

Our research aims at developing a semi-virtual DT approach that supports companies in facilitating semi-virtual teamwork regarding creative innovation projects. In our experiment, we tested a semi-virtual DT approach in comparison to an analog one. For the evaluation of our research, we introduced SMM as a measurable construct to make a statement on shared understanding, satisfaction, and perceived effectiveness. Additionally, we asked the participants of the EG to state, which functionalities of the digital whiteboard were used most frequently in order to answer which functionalities of the tool support semi-virtual DT. Furthermore, we introduced three existing media theories – MRT, MNT, and MST – to be able to evaluate the fit and functionality of the digital whiteboard that was used during the experiment.
Based on the theoretical basis at the beginning of our paper, we discuss the results of the survey in regard to our propositions.

In proposition 1, we predicted that a semi-virtual DT workshop leads to a low shared understanding of teams in contrast to an analog setting. We can outline that this proposition 1 is false, since the results show an insignificant difference and the level of shared understanding is minimally lower in the EG than in the CG. The results evoke that the level of shared understanding in the semi-virtual DT setting was comparably high, which indicates a positive, successful collaboration. The results of the experiment are opposing with findings from vam Knippenberg and Schippers (2007) who state that virtual collaboration for a short-time frame might negatively contribute to the team's creative performance. Our experiment structure and setting of a time-restricted semi-virtual DT workshop that is based on creative interaction shows a high level of shared understanding. The results are, therefore, in line with Mathieu et al. (2008) who state that virtual collaboration can positively contribute to creative teamwork.

In line with proposition 1, we argued in proposition 2 that a low level of satisfaction can be found in semi-virtual DT workshops in comparison to an analog one. The results disprove our proposition 2, since the rated level of satisfaction is high. This is also contrary in regard to findings from Martins and Shalley (2011) who state that multiculturalism affects the process of virtual collaboration negatively. Our experiment included collaboration of people from 27 countries who rated a high level of satisfaction concerning their teamwork. The participants of the EG rated their perceived satisfaction 1.5% less in comparison with the CG, which indicates that neither the multicultural team constellations nor the semi-virtual collaboration negatively impacted the DT workshops.

In proposition 3, we predicted that a semi-virtual DT workshop is perceived with low effectiveness compared to an analog setting. Again, the proposition 3 is disproved by the results of the experiment. The level of perceived effectiveness of the experiment's participants is high in the CG as well as in the EG. The results of the experiment are in line with the assumptions of Gilson et al. (2015) who propose that negative effects due to virtual collaboration are less dominant in teams that represent younger generations. According to the participants' ages ranging from 19 to 22 years, a negative effect regarding a perceived level of effectiveness can be explained due to the generation's familiarity with ICT.

The reflection on our propositions in comparison with the results from the experiment, show that a semi-virtually performed DT workshop does not have negative effects on the shared understanding, satisfaction, and perceived effectiveness of the participants. The survey shows that all items of the SMM knowledge structure 'team task, goal and performance requirements' reached a high level, which is an indicator for successful collaboration. This finding is supported by Bittner and Leimeister (2014) who state that for SMM, especially in a diverse team constellation, a high level of shared understanding is an essential indicator for success. Accordingly, our research question 'How is the level of SMM in a DT workshop impacted when teamwork is performed in a semi-virtual setting?' can be answered with a positive résumé.

Concerning our research question whether a digital whiteboard is an appropriate support for semi-virtual DT workshops, we can argue that our chosen digital whiteboard Mural.co creates an overall satisfactory support. This is in line with the questioning of the experiment's participants of the EG. The results also coincide with findings from Ju et al. (2006) who state that flexibility of collaborative visualization, which a whiteboard offers, supports the building of SMM.

Furthermore, all EG teams came to a satisfying output at the end of the semi-virtual DT workshop, which indicates that the usage of Mural.co supported the process toward a satisfactory output. This is in line with findings from Gilson et al. (2015) who summarize that a constant level of creative and multicultural collaboration can be achieved regardless the choice of ICT.

Our survey of the EG, moreover, delivered information on the functionalities a digital whiteboard needs to inherit in order to support the development of SMM in a semi-virtual DT workshop. The results show that post-it notes, text insertion, and shapes and connections were the most preferred functions used in virtual team collaboration. Additionally, the chat function of Mural.co was rated most common. Although, the participants were free to use any additional audio-visual application in regard to personal claims, most participants used the integrated chat function of our suggested digital whiteboard. As stated earlier, findings from literature indicate that if participants use well-known ICT, a level of comfortableness positively influences team interaction (Martins and Shalley 2011). The results of the experiment indicate that comfortableness toward ICT usage might also be achieved via integrated functionalities of one application such as a usually commonly-known chat function.

Other functionalities provided by Mural.co such as a voting system, photo insertion, predefined templates, and icons were in comparison less frequently used. We propose that these less used functionalities might become more important, when different tasks during virtual collaboration are performed. Photo insertion, for example, might play a more important role, when other methods such as the creation of storyboards are applied.

Eventually, the rating of the participants on the usage of specific functionalities reveal a response to our research question 'Which functionalities of a digital whiteboard are needed to appropriately support the development of SMM in a semi-virtual DT Workshop?'.

In conclusion, we can reveal that our propositions, which are based on the MNT, cannot be supported. The results of the experiment show positive levels of SMM, which indicate that cognitive processes were not hindered during semi-virtual collaboration. Accordingly, we disprove the relation of MNT in the context of our experiment.

Furthermore, we cannot verify a connection to MST since the evaluation did not measure the speed of synchronicity of virtual communication.

Based on the discussion, we rather propose that the success of the semi-virtual DT workshops is in line with MRT, as the evaluation of the applied digital whiteboard revealed a rich usage of functionalities that are provided by the software and used by the experiment's participants.

9.7 Conclusion

This paper examined whether the innovation approach DT, which is usually performed in an analog setting, can also be performed in a semi-virtual setting.

We, therefore, conducted an experiment that followed the requirements of a DT approach. On the basis of the psychological construct of SMM, we evaluated our semi-virtual DT approach in comparison to an analog DT workshop. The discussion on existing media theories served as an underlying foundation for the evaluation of our applied software, a digital whiteboard.

In summary, we can outline that our propositions have been proven wrong. The results show that there are no negative effects of the level of SMM when performing DT semi-virtually. This, consequently, disproves our assumption that an ICT-supported collaboration hinders cognitive processes, as predicted according to MNT.

This research rather reveals that a semi-virtual DT workshop can lead to high levels of shared understanding, satisfaction, and perceived effectiveness. We argue that the applied digital whiteboard supports a creative semi-virtual collaboration due to the advanced functionalities. Based on this finding, we draw a connection to MRT.

Furthermore, we admit that our research has limitations concerning the number participants. Additionally, as we aim at developing a semi-virtual DT approach for the benefit of companies to improve innovation development, an experiment with employees would be of advantage. Even though, there is a need for further research to prove different conditions of semi-virtual DT, this research shows that a strictly designed semi-virtual DT workshop with the support of appropriate ICT leads to a successful collaboration, which is a first step for improving business challenges in this context.

9.8 Acknowledgements

This study is part of the project 'DETHIS – Design Thinking for Industrial Services', funded by the Federal Ministry of Education and Research (BMBF) of Germany, Grant 02K14A140.

10. Paper 5

Can Virtual Design Thinking Be Performed Satisfyingly?

Beke Redlich, Christoph Lattemann, Simon Fischer

This paper is printed with permission of the above-mentioned authors by a 'Declaration of Consent' signed on behalf of the IRC / Jacobs University Bremen gGmbH.

10.1 Abstract

Computer-mediated collaboration becomes increasingly important in various corporate areas, also in innovation management. In this paper, we analyze the effects of Design Thinking (DT), an agile and creative innovation approach, on participants' satisfaction when performed virtually. We compare analog with virtual DT (VDT) workshops executed by diverse team members from inside and outside medium-sized companies. We identify effects that arise with creative, collaborative, and virtual innovation development by applying a socio-cognitive view.
Our results reveal that despite an increased participant's exhaustion, VDT leads to high perceived satisfaction and Shared Mental Models. Furthermore, VDT shows a decline of perceived satisfaction over time, which we explain with the McGurk Effect and the Media Richness Theory. The insights from this research help to improve the settings of VDT. This research might also reveal valuable insights for the settings (e.g. timing, applied tools) of other creative, collaborative, and virtual workshop settings.

10.2 Introduction

Nowadays, collaboration among firms is becoming increasingly important and complex at the same time due to the need to integrate multiple internal and external stakeholders as well as their knowledge and experience in development processes (Batarseh et al. 2016). Corporate collaboration is performed for different purposes and with a diverse set of team members in different settings (Brown 2009). Initiating the collaboration among multiple stakeholders – e.g. employees, external experts (open innovation), and customers (customer integration) – challenges corporate resources such as time and costs as well as participants' competencies when it comes to virtual collaboration. As geographically dispersed corporate teamwork becomes increasingly essential, questions on satisfaction, successfulness, and usefulness of specific collaboration settings turn into important subjects for research and practice (Gilson et al. 2015).
To keep pace with the rapidly changing and globalized markets that companies face, they need a suitable innovation and virtual collaboration approach. Challenges in the innovation development arise since a collaborative, creative, and user-centered development process needs to take stakeholder interdependencies and suitable methodological approaches into account to allow for co-creation (Frow et al. 2015, Lattemann and Robra-Bissantz 2005). There is variety of possible collaborative approaches existent that can be used for innovation development in teams, such as single creativity techniques or agile methods. Design Thinking (DT) is one of these approaches that stands out in terms of being strictly systemized, which offers an adequate foundation to understand the required collaboration setting. DT is defined as being creative, multidisciplinary, and iterative through its process, methods, and mindset-perspective that involves a complex

collaboration mode in workshop-settings (Brenner et al. 2016, Carlgren, Rauth, et al. 2016, Stickdorn and Schneider 2012). In this paper, we refer to DT, as it is an increasingly applied creative, collaborative and user-centered innovation approach already applied in renowned multinational enterprises (Brown 2009). Nonetheless, the workshops are usually exercised in an analog, face-to-face-setting and are, yet, not applicable in a complete technology-based solution (Furmanek and Daurer 2019, Gräßler et al. 2017).

Against this backdrop, we defined a concept for virtually performed DT and compiled an artifact based on Design Science Research (Hevner et al. 2004), which encompasses an audio- and videoconference tool for communication and digital whiteboards for collaborative visualization. We aim at analyzing the effects of the collaboration mode when DT is performed virtually by presenting an experiment with two companies. The experiment compares three analog DT workshops with two Virtual Design Thinking (VDT) workshops, which were completely supported by Computer-mediated Collaboration (CMC) tools. The three analog DT workshops act as a control setting to assemble a solid ground for comparison and to recheck the appropriateness of the VDT approach. All five workshop settings dealt with the user-centered innovation of services and followed the same DT concept that is presented in a subsequent section.

We examine how a virtually performed DT setting affect participants' perceived successfulness as past research has shown that there is still no quantitative approach toward measuring the success of DT, although its successfulness is legitimized in practice (Carlgren, Rauth, et al. 2016). This is why we measure the success of DT in our research by applying a process and performance perspective instead of an output-perspective (Schmiedgen et al. 2016). Since the process and performance of a DT workshop is fundamentally dependent on collaboration, we refer to perceived successfulness as the sum of a positively perceived experience (satisfaction) of each participant while and after a (V)DT workshop. Hence, we apply a socio-cognitive view on creative, collaborative, and virtual innovation development by the application of DT.

For the evaluation of group work in the experiments, we refer to the psychological construct of Shared Mental Models (SMM) in order to draw conclusions on the successfulness (team task, team goal, performance requirements, and perceived satisfaction of team members with the innovation process) of VDT (Dennis et al. 1996, Johnson et al. 2007, Maynard and Gilson 2014, Santos et al. 2015, de Vreede et al. 2012). Furthermore, we introduce the Media Richness Theory and the McGurk Effect to explain our results by established theories (Daft and Lengel 1986, MacDonald 2018, McGurk and MacDonald 1976).

Our experiment is based on real-life challenges of two medium-sized service companies located in German metropolitan cities and refer to actual innovation undertakings, which places this research in an authentic setting. Nonetheless, due to the limited number of five workshops with a respectively small number of total participants, generalizations of our findings should be drawn with caution.

In the next section of this paper, we briefly present the theoretical grounding of DT and virtual collaboration to yield toward our experiment setting. This is followed by the presentation of our evaluation approach and the deduction of our propositions. Afterwards, we shed light on our applied methodology and the experiment design, followed by the presentation of our results, the discussion, and conclusion. Accordingly, we address the research question 'How are process requirements and perceived participants' satisfaction influenced when DT is performed in a virtual setting?'.

10.3 Virtual Design Thinking

Until lately, DT was solely performed in analog, face-to-face settings due to its complex collaboration mode (see figure 23). Nonetheless, performing DT virtually is a necessary evolution since the efforts of analog meetings in a globalized world impede the application of this successful innovation approach. Therefore, a general understanding on virtual collaboration research is presented. Moreover, as a foundation for our methodology and experiment, SMM, the Media Richness Theory as well as the McGurk Effect are presented to set a ground for an in-depth elaboration on socio-cognitive effects through the performance of VDT.

10.3.1 Design Thinking

In our experiment, we apply the increasingly popular DT approach as the collaboration environment because it addresses firms' requirements regarding open-mindedness and user-centeredness to reach innovative originality (Brown 2009). DT is a systematic approach for innovation development that strongly relies on collaboration of multidisciplinary and diverse teams (Carlgren, Rauth, et al. 2016). DT consists of three overarching elements – process, methods, and mindset – that jointly constitute DT in an iterative and time-restricted workshop setting (Brenner et al. 2016). The core of DT is targeted in developing user-centered solutions (Brown 2009). This is reached by the application of the DT process, which inherits different reasoning modes – induction, abduction, and deduction – and thinking modes – divergent and convergent –, which are practiced by the application of single methods from diverse disciplines, such as observing from Ethnography, defining a point of view from Design Science, or prototyping from Engineering (Kolko 2010, Redlich, Dorawa, et al. 2018, Tschimmel 2012, Wylant 2008). There are different versions of the DT processes used in practice, but they all inherit the major purposes such as understanding and observing a design challenge as well as prototyping of an idea (Brenner et al. 2016, Stickdorn and Schneider 2012, Thoring and Müller 2011). We decided to apply a DT process that consists of the phases design challenge, understand, observe, point of view, prototype, test, and implementation to comply with the needs of corporate service innovation (Redlich, Becker, et al. 2019).

Any chosen DT process is provided with suitable DT methods, like stakeholder analysis or persona, which serve as content-specific guidelines for the user-centered innovation development (Stickdorn and Schneider 2012). DT starts mostly with a problem statement (design challenge), which means that the type of the outcome – whether product, process, and/or service – might only become apparent while ideating. This has implications for the choice of method(s) for prototyping as the innovation of services require other methods than products (Potthoff et al. 2018).

The DT mindset frames the mode for collaboration (Brenner et al. 2016, Carlgren, Rauth, et al. 2016). Being open-minded, interaction without hierarchy, more showing - less telling, and building empathy for others are, among others, the preferred collaboration style in DT to foster creativity and innovative outcomes (Carlgren, Rauth, et al. 2016, Dosi et al. 2018, Elsbach and Stigliani 2018). The overall DT environment is created by the interplay of process, methods, and mindset, enforced by a trained DT coach, who conceptualizes the workshops and guides through the collaborative setting. Hence, the complexity of collaboration in DT (see figure 23) is assembled through the application of…

(1) …three different modes of reasoning (induction, abduction, deduction), that challenges participants' cognition;
(2) …different thinking modes (divergent, convergent), which can be interrupted by iterative steps;
(3) …a large set of individual methods that are applied and require compliance with given rules;
(4) …time pressure to complete the advised methods in a given time frame, and
(5) …collaborating with team members with different backgrounds (education, gender, age, nationality, etc.).

Additionally, past research has shown that the space where DT is performed effects the collaboration mode. This is especially true for various communication channels (Redlich, Dorawa, et al. 2018). Communication in DT workshops is usually a combination of direct group discussions, one-to-one/side-talks, as well as visual communication with the help of whiteboards or similar visualization media (6) (Furmanek and Daurer 2019).

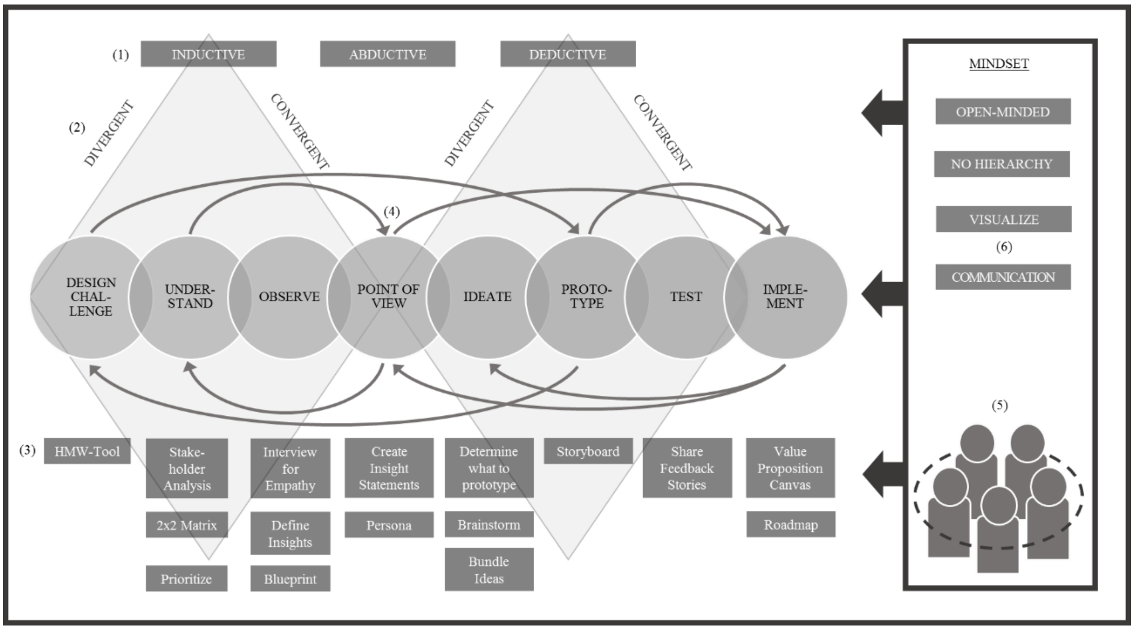

Figure 23 Paper 5 – Elements of complex collaboration in DT

Figure 1 visualizes the complex setting of DT, by showing the interplay of DT process, methods, and mindset, as well as requirements which come with the application regarding thinking- and modes of reasoning during the interaction of diverse teams. Summarizing, this figure illustrates the requirements of collaboration in DT that serve as a basis regarding the necessities for a virtual performance.

10.3.2 Virtual Collaboration and Design Thinking

With the intention of performing DT location-independent, a virtual collaboration environment is necessary. Virtual collaboration in general is constrained by the use of CMC, which oftentimes integrate audio- and videoconferencing for substituting face-to-face communication (Santos et al. 2015). Hence, VDT is faced with challenges such as the competencies and comfort of Information- and Communication Technology (ICT) usage, hard- and software requirements, and available internet connection, which stem from the application of CMC, and accordingly have to be taken into consideration when performing VDT (Lojeski et al. 2007). A few approaches toward virtual, digital, or remote DT have been performed over the past couple of years (Gräßler et al. 2017, Gumienny et al. 2011, Lattemann et al. 2017, Rao 2018, Redlich, Dorawa, et al. 2018, Rive and Karmoker 2016, Wenzel et al. 2016). Wenzel et al. (2016) categorized the different research approaches on VDT in his work into a technical and a human-centered perspective. The technical perspective refers to ICT that is examined in terms of appropriate infrastructure to enable collaboration from a more functional view and can be found in Gumienny et al. (2011), Rive and Karmoker (2016), Wenzel et al. (2016), Gräßler et al. (2017), Lattemann et al. (2017), and Rao (2018). The human-centered perspective refers to requirements and effects in terms of collaboration while performing DT virtually. This can be for example found in research that examines the virtualization of certain parts (phases or methods) extracted from the general DT approach, likewise in Potthoff et al. (2018), Siemon et al. (2018), and Redlich, Dorawa et al. (2018). Following, there is no research that inherits a human-centered perspective on the holistic VDT approach.

Thus, we follow a human-centered approach that analyses the socio-cognitive aspects of collaboration in our VDT setting (Wenzel et al. 2016). Whereas the term ‘human-centered’ can refer to any kind of perspective concerning the individual or groups such as competencies or cognition, we apply the more specified version of human-centeredness, referring to the socio-cognitive view. The socio-cognitive view deals with a holistic examination of individual cognition as interplay of the brain, mind, and the environment, which is influenced by social and cultural factors that can be regarded with the interaction of the artificial such as CMC (Hjørland 2002). CMC represent the connection of human communication via ICT, which is a social act that directly refers to cognition (Hjørland 2002). Following, it is important to define and test an appropriate artifact, which serves the process- and performance related issues and the need of participants' satisfaction. Apart from that, past research connects the aspects of the socio-cognitive view with mental models, also when it comes to a team perspective (Bittner and Leimeister 2014, Lind and Zmud 1991, Mathieu et al. 2000). Hence, the complex collaboration mode of DT as well as the general challenges that come with CMC usage need to be reflected when examining VDT (Furmanek and Daurer 2019, Lojeski et al. 2007, Wenzel et al. 2016).

Moreover, Munkvold and Zigurs (2007) state that specific settings of virtual teams – who work under time pressure and who have specific communication requirements like in VDT – need to be examined in order to identify and evaluate their necessities for success. In line with this, we chose to define an artifact that is based on an audio- and videoconferencing tool and a digital whiteboard. With the support of the artifact, we simulate the communication and collaboration environment, which usually exists in an analog setting. To evaluate the performance of VDT, we refer to the construct of SMM, Media Richness Theory, and the McGurk Effect.

10.3.3 Shared Mental Models

It is most common in the field of Information Systems to apply interdisciplinary evaluation approaches to test artifacts (Bittner and Leimeister 2014, Hjørland 2002, Lawrence et al. 2010). We decided to apply the psychological construct of SMM to show the successfulness of team collaboration and processes within CMC. SMM are shared internal representations of collective situations that several individuals are confronted with (Maynard and Gilson 2014, de Vreede et al. 2012). SMM have been found to make a contribution on the successfulness of collaboration concerning the interdependent aspects of collaboration regarding (1) team task, (2) team goal, and (3) performance requirements (de Vreede et al. 2012):

(1) The aspect 'team task' refers to the shared understanding of a challenge the team is confronted with, which is comparable to the design challenge within DT as presented earlier. The higher the level of shared understanding in regard to a team's task is, the better are the prerequisites for a successful collaboration.
(2) The aspect 'team goal' refers to a shared understanding of the objective that a team wants to reach jointly. Following, the higher the level of shared understanding toward a common goal is, the more likely it is to succeed as a team. The major goal in DT refers to user-centered innovation.
(3) 'Performance requirements' are the accumulation of functional, human, and methods' needs that are necessary to perform the team task and to reach the team goal. The higher a shared understanding toward performance requirements is, the more likely is a successful performance. In DT the application of performance requirements (process, methods, and mindset) are accompanied by a DT coach.

There are several reasons why the application of SMM is suitable as an evaluation approach for our VDT artifact. Firstly, SMM are commonly applied to evaluate the performance of virtual collaboration under specific settings (Munkvold and Zigurs 2007, Santos et al. 2015). Moreover, research shows that a higher level of SMM in creative (virtual) settings positively influences the successfulness of teamwork in e.g. innovation settings (Davison and Blackman 2005, Kratzer et al. 2004, Lojeski et al. 2007). As creativity and collaborative visualization, like in DT, are frequently linked, it is of interest that research reveals that collaborative visualization can enhance the building of SMM, also in virtual collaboration (Siemon et al. 2017). Additionally, the construct of SMM is suitable for measuring perceived satisfaction of team members in a collaboration setting. This allows for an evaluation of VDT in the light of team members' perceived satisfaction, which reflect their well-being in terms of a socio-cognitive view (Munkvold and Zigurs 2007). To assess the fit of SMM concerning task-, performance-, and process-related team collaboration, as well as visual communication, we have defined a survey based on items defined in related research (Dennis et al. 1996, Johnson et al. 2007, Santos et al. 2015, de Vreede et al. 2012).

10.3.4 The Media Richness Theory and the McGurk Effect

Collaboration in a virtual setting or CMC require the usage of ICT, which affects the cognitive processes of participants, specifically communication (Hollan et al. 2000). Over the past decades, different theories and effects were introduced that support a generalized understanding of challenges and opportunities when it comes to CMC. While examining the level of SMM toward joint representations of task, goal, and performance, we can reveal whether a satisfaction of each aspect refers to either positive, neutral, or negative tendencies. Nonetheless, reasoning the results of our experiment requires a linkage toward findings from theory. One theoretical approach that is relevant for our research derives from Daft and Lengel (1986), who introduced the Media Richness Theory (MRT), which describes that in situations of rather complex, corporate communication, likewise in team communication in innovation settings in contrast to one-to-one talks, richer communication media is in principle more appropriate to create an effective communication setting. Furthermore, the authors explain that this specific type of

communication is challenged by the so called 'Information Richness', which describes a change of the meaning of certain information over time due to a change of setting that might lead to equivocation (Daft and Lengel 1986, p. 560). Hence, the richer a medium/CMC artifact is, the better the prerequisite of a shared representations toward a common topic/problem to create a satisfactory collaboration. Against this backdrop, we expect to link the results of SMM toward MRT in order to find out whether the appropriate level of richness regarding our artifact is suitable. And, hence, has a positive or at least neutral influence in comparison to analog DT.
However, the application of ICT for collaboration – no matter how complex a setting is – can also be faced with issues of synchronicity. The cognitive process of (collaborative) communication can be challenged by irregularities that occur during transmission of information, which was found by the researchers McGurk and McDonald (1976). The so called 'McGurk Effect' derives from the field of Developmental Psychology and revealed that speech is not solely connected to the sense of hearing but also to seeing (McGurk and MacDonald 1976). Moreover, since 1976 a large number of experiments with CMC proved that communication is disturbed by lag-times that distort the synchronicity of speech, hearing, and vision. The lag-times can lead to misunderstandings in communication and demands an increased concentration and attention of the participants in the communication process. Applying audio- and videoconferencing over a longer period (e.g. several hours over five days like in our experiment setting) might lead to exhaustion and decreased attention due to the high efforts of cognition (Karpova et al. 2009). Hence, we will reflect the results of the level of SMM regarding a McGurk Effect.

10.4 Propositions

Based on the theoretical insights, we derive propositions to shed light on the effects, which are entangled with the performance of VDT. According to Gibbs et al. (2016), who categorized different ways of virtual team research, we follow the performance approach by exploring socio-cognitive aspects of corporate, collaborative, virtual innovation development and its inherent challenges with technology use. Initially detached from the McGurk Effect, we focus on effects that are caused by the virtual setting and which relate to team task, team goal, performance requirements, and team members' satisfaction with the collaboration (de Vreede et al. 2012).
Our propositions directly refer to the specific setting of our experiment, i.e. virtual collaboration for innovation development in a time-restricted (workshop) manner, specifically VDT. Munkvold and Zigurs (2007) argue that group diversity in terms of team constellation and mindsets have an influence on the success of virtual teams, which we want to explore with the level of SMM. Since our experiment teams are multidisciplinary and diverse, we propose that the development of shared task and goal perspectives are challenged especially in the case of virtual collaboration and the use of our artifact. Based on these theoretical considerations, we derive the following propositions.

Proposition 1: Virtually performed DT leads to lower levels of SMM in comparison to analog settings, specifically for the measure 'team task'.

Proposition 2: Virtually performed DT leads to lower levels of SMM in comparison to analogs settings, specifically for the measure 'team goal'.

Following, we suggest that the level of SMM of team task and goal is negatively affected by our setting of virtual collaboration, hence ICT usage. Since our setting inherits a solely collaborative manner, we do not take individuals into consideration but the team as such. This is in line with Kratzer et al. (2004) who argue that individuals align in creative development processes, which supersedes the necessity for taking an individual level into consideration.
We further propose that performance requirements of our virtual development teams are affected by the means of collaboration. Accordingly, extreme time-restrictions, like it is often given in DT, lead to the adaptation of collaboration styles in virtual teams (Munkvold and Zigurs 2007). As the VDT approach is well structured and accompanied by a DT coach who supports team interaction, it might be the case that performance requirements are positively influenced due to a streamlined interaction through ICT usage. This perspective is in line with Bataseh et al. (2016) who summarize that virtual teamwork for the purpose of innovation development is encouraged by a rich collaboration environment. We therefore propose that virtual performance leads to a positive level of performance requirements, which is the foundation for a mutual procedure within the team (Maynard and Gilson 2014).

Proposition 3: Virtually performed DT leads to higher levels of SMM in comparison to analog settings, specifically for the measure performance requirements.

Concerning the overall team performance, we propose that higher levels of perceived satisfaction will be reached by virtual teams because the DT environment enhances the mode of collaboration (Carlgren, Rauth, et al. 2016). Research shows that well-being, social, and cognitive (socio-cognitive) aspects of virtual collaboration has an influence on the performance (Munkvold and Zigurs 2007). We propose that well-being is reflected in VDT, and thus takes the perceived satisfaction of team members into consideration.

Proposition 4: Virtually performed DT leads to high levels of SMM, measured by the perceived satisfaction of team members.

In the following section, we present our methodology and experiment design that relies on a comparison between analog and VDT.

10.5 Methodology and Experiment Design

Following the Design Science Research (DSR) methodology, we built an artifact that represents the communication mode in analog DT workshops (Hevner et al. 2004). Based on the analysis of a series of analog DT workshops with service companies, we identified the required ICT-based communication channels for a virtual collaboration of (V)DT. Communication in an analog setting is rich in terms of synchronous visual and verbal communication. Our artifact consists of an audio- and videoconferencing tool – adobe connect – and a digital whiteboard. To exclude tool-specific challenges in the experiment, we used two different whiteboards with similar functionalities in two corporate workshop settings (Kniberg 2018, Suarez-Battan 2012). Functions such as drawing freely, inserting post-it notes, forms, connections, and icons are provided by both digital whiteboards.
In our experiment design, we compare analog with virtual DT workshops. The reflections on the analog workshops serve as reference points to assess the performance of virtual workshops. All

workshops followed the same concept. Team members are internal and external stakeholders of two companies and the level of SMM was assessed by applying previously developed measures. Additionally, we performed semi-structured group interviews directly after the virtual workshops (direct feedback rounds) to include the opinion of individual and team performance from all participants. The feedback was guided by a researcher and lasted approximately 15 minutes in total after both virtually performed workshops.

10.5.1 The Workshop Concept

The workshop concept consists of the phases 'Design Challenge', 'Understand', 'Observe', 'Point of View', 'Ideate', 'Prototype', 'Test', and 'Implementation', see also figure 24. For each phase, we have chosen one to three creativity methods, which are appropriate for the development of service innovation (Stickdorn and Schneider 2012).

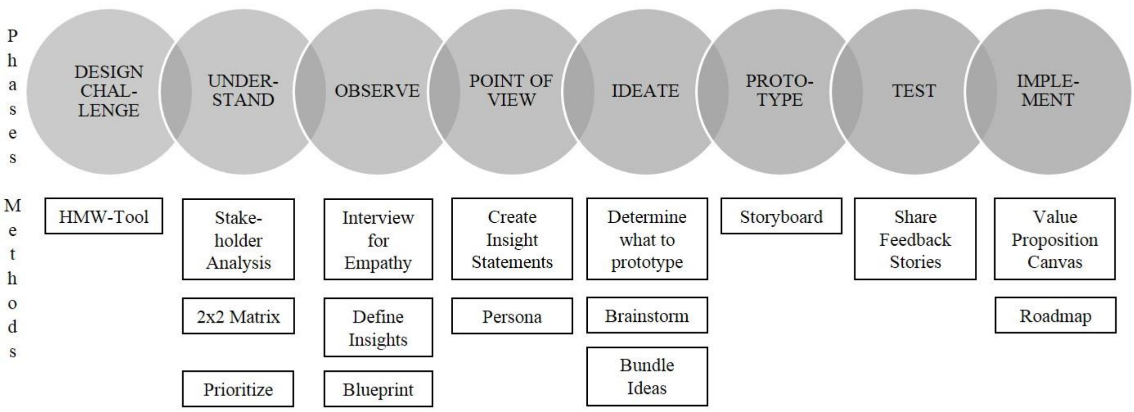

Figure 24 Paper 5 – Workshop concept for analog and Virtual Design Thinking

Figure 24 illustrates the DT workshop concept in terms of the applied DT process (phases) and methods, which were conceptualized prior to the execution of the experiment. Figure 24 differs from figure 23 in terms of the aspects that need to be conceptualized beforehand. The DT workshop concept serves as a guideline for participants as well as for the coach. Hence, in this context, the concept mirrors the experiment design and procedure. The concept was applied in the analog and the virtual setting.

The analog workshops took place in a dedicated DT lab and without the use of any electronic media. The virtual workshops were performed location-independent. The virtual workshops applied the depicted artifact. In total, the workshop settings lasted 3 to 3.5 hours per day over 5 days. All workshops were moderated by the same, experienced DT coach and had a service innovation design challenge as initial problem statement.

10.5.2 The Participants and Procedure

The participants of the experiment were recruited from two previously selected service companies, which led to workshop participants who had DT experiences in advance to the experiment. In each workshop, participants came from different departments of one company to ensure an interdisciplinary perspective. However, the workshops were conducted with different companies. Further, external experts were invited to contribute as team members to the innovation process. Overall, three analog DT workshops were performed with alternating teams from two companies as well as external experts (Total number of participants 16; Team size Ø 5.33; 12 male; 4 female, Ø 39.06 years).

For the purpose of assessing the performance of VDT, we created two virtual workshops; one for each company. Hence, both groups consisted of internal company members with additional external team members. According to this, we conducted the VDT workshop twice with each company separately. In the following, we refer to team 'Virtual 1- V1' and 'Virtual 2- V2'.

Team V1 had overall 5 team members, with 4 internal employees from different departments such as services and quality management and one external expert from a university (3 male; 2 female; Ø 37.5 years). Team V2 had overall 3 team members, with 2 internal employees from different departments such as service innovation and technical documentation as well as an external expert from a university (2 male; 1 female; Ø 32 years). All experiment participants had different levels of IT savviness, ranging from professional to basic knowledge on IT usage.

10.5.3 Measures

The chosen measures are derived from research on SMM. de Vreede et al. (2012) defined four different knowledge structures of SMM. We chose to apply the knowledge structure 'team task, team goal, and performance requirements', and 'perceived satisfaction' to comply with our performance perspective (Dennis et al. 1996, Santos et al. 2015, de Vreede et al. 2012). In total, we identified 12 items for the assessment of the workshops – 3 for each measure.

For the measures 'team task', 'team goal', and 'performance requirements' we derived items based on Johnson et al. (2007) and Santos et al. (2015). Additionally, we compiled items for the measure 'satisfaction', which are based on Dennis et al. (1996) and Santos et al. (2015). The items were included in a digital survey and were measured on a 5-point-likert scale (1 strongly agree to 5 strongly disagree). The participants were asked to fill out the survey twice. Once in the middle of the DT process (T1) and a second time directly after the official end of the collaboration (T2). The same survey was used for the analog and virtual workshops.

10.6 Results

Based on the results of the survey, we will firstly present the descriptive data that compares the results from the analog workshops (A) with the results from the virtually performed workshops (V). The Cronbach's alphas for the items were all above 0,7, for a detailed presentation of Cronbach's alpha see Siemon et al. (2017). The following table 10 shows that the mean values of the analog workshops present an overall high to very high level of SMM.

Measure	$Mean^A$	$Mean^V$	SD^A	SD^V
Team Task	4.1	3.7	.51	.42
Team Goal	4.2	3.8	.34	.5
Performance Requirements	4.4	3.6	.34	.59
Satisfaction	4.3	3.9	.48	.41

Table 10 Paper 5 – Descriptive data: Comparison of analog and virtual workshops

According to the non-normal distribution and the small number of participants in our experimental setting, we calculated a Mann-Whitney U Test (U) for comparing the results of the analog and virtual performance. As presented in table 11, there is a significant difference between the levels of all four measures in favor of the analog performance of the DT workshops. The statistical significance is supported by the medium and strong effect size (d).

Measure	U	d	p
Team Task	343.5	0.562	.030**
Team Goal	368.5	0.816	.001***
Performance Requirements	362.5	0.957	.009***
Satisfaction	351.5	0.722	.017**

Table 11 Paper 5 – Mann-Whitney U Test of analog and virtual workshops

Furthermore, these results indicate a perceived successful collaboration among team members in the analog DT workshops. We define a low level of SMM if the average Likert-scale score is below the midpoint (3) and a high level of SMM if the average Likert- scale score is above the midpoint (Siemon et al. 2017). Our statistical evaluation revealed that all measures receive high levels of SMM in both points in time, which shows that an analog performance of DT workshops leads to constantly high levels of team task, team goal, performance requirements, and satisfaction. The high level of SMM in the analog workshop are the reference point for the assessment of the virtually performed workshops.

For a more detailed assessment of the virtual workshops, we will present the mean values and standard deviations of the survey results for V1 (table 12) and V2 (table 13) for both points in time (T1 and T2).

Measure	T1	T2	dT^1	dT^2
Team Task	3.8	3.6	.68	.63
Team Goal	3.8	3.5	.86	.52
Performance Requirements	4.3	3.5	.49	.64
Satisfaction	4.1	3.8	.52	.68

Table 12 Paper 5 – Descriptive data: Virtual workshop with V1

The mean values of the survey results of team V1 for the two points in time V1-T1 and V1-T2 are shown in table 12. The results for ‘team task’ are similar for V1 and V2 (3.8 in T1 and 3.6 and 3.7 in T2). The results are above median (midpoint of 5-point-likert scale = 3) and indicate a high level of SMM in understanding the team task. The measure ‘team goal’ shows a similar pattern. The results for ‘performance requirements’ drop from V1-T1 (4.3) to V1-T2 (3.5) by 0.8, although both values show a high level of performance requirements. The values for the measure ‘satisfaction’ are similar for the teams V1 and V2. Both results show that the team members were satisfied in both points in time (T1 and T2).

Measure	T1	T2	dT1	dT2
Team Task	3.8	3.7	.67	.71
Team Goal	4.6	3.6	.53	.53
Performance Requirements	4.3	3.4	.5	.53
Satisfaction	4	3.7	0	0,5

Table 13 Paper 5 – Descriptive data: Virtual workshop with V2

The measure 'team task' shows similar values for V2-T1 and V2-T2. The mean values for 'team goal' and 'performance requirements' vary among the two points in time quite drastically. The values drop by 1.0, and 0.9 respectively, from V2-T1 and V2-T2. Additionally, the values for satisfaction drop by 0.3 points from V2-T1 to V2-T2.

Overall, the results show that the workshop participants created high levels of SMM for the stated measures for both points in time. Surprisingly, the values for SMM for the measures 'team goal' and 'performance requirements' dropped from T1 to T2 for V2. Although all workshops are rated with high levels of SMM, the comparison of the results of the analog and virtual performed workshops show that there is a significant difference in the level of the measures between analog and virtual performance. Both virtually performed workshops show insignificant differences. Moreover, the results of the analog workshop show constantly high levels of SMM over the complete workshop in both points in time. This is different in both virtually performed workshops. The level of SMM dropped over time in the virtually performed workshops from T1 and T2.

Additionally, the feedback, in form of semi-structured group interviews, conducted after the virtual workshops, revealed that participants perceived the VDT in comparison to the analog collaboration much more exhausting because of a lower level of mobility, due to the fact that they are leached by headphones in front of screens. Interestingly, the immobility was perceived as partly positive since it made the participant focused on the task, which led to the participants' perception of being more effective.

Further, the participants reported a perception of being much more exhausted while and after a virtual workshop. This is caused by the screen size, which could not display all activities of every team members at the same time. A small screen makes it complicated to keep up pace with the process because one cannot always trace where the other team members are acting on the digital whiteboard. Furthermore, the participants described that team members with low levels of IT competences were challenged and needed support from IT experts to effectively participate in the virtual setting. This was negatively perceived and distracted the flow of the innovation process. Moreover, individual problems with the ICT tools and technical disturbances (e.g. internet connection caused time lags in communication) led to the perception of even higher time pressure in both virtual workshops.

All participants agreed that the virtual performance in comparison to the analog workshop was perceived as more effective but less fun. Due to the given time restrictions in a VDT workshop, communication is identified as being intense, exhausting, and demands perseverance from all team members during the process.

10.7 Discussion

Based on our theoretical examination on DT in the light of virtual collaboration, SMM, MRT, and the McGurk Effect, we derived propositions that will be discussed vis-á-vis the results of our experiment. In our proposition 1 and 2, we stated that the execution of VDT leads to lower levels of the SMM measures 'team task' and 'team goal'. According to our results, both propositions are confirmed. The values for the analog workshops are higher in comparison to the virtual workshops. Nonetheless, the levels of both measures are above median/high, which indicate that the diversity of team members had no negative effect on virtual team performance. This is in line with Munkvold and Zigurs (2007) who argue that rich CMC tools, like compiled in our artifact, support collaboration with members of different working styles and cultures. The results are as well reinforced by the findings from Kratzer et al. (2004) in underlining that the consideration of the individual level in virtual collaboration is not needed, because SMM is correspondingly an indicator for successfulness (Munkvold and Zigurs 2007).

For the validation of proposition 3, we discussed whether the strong and professional coaching during VDT, as well as a structured timing positively influences on performance requirements (Batarseh et al. 2016, Munkvold and Zigurs 2007). Reflecting our results, we can adhere that the levels of the SMM measure performance requirements are high but lower than in analog workshops. Accordingly, our proposition 3 cannot be confirmed. But since the level of SMM performance requirements is still high, this result is in line with the argumentation of Batarseh et al. (2016) that rich communication environments, likewise in our artifact, supports virtual and creative innovation teams in general.

Proposition 4 states that due to the DT environment, which fosters the DT mindset and facilitates the application of the specifically designed DT concept, the level of perceived satisfaction with the process is supposed to be high. The results confirm this proposition. Since satisfaction is correspondently an indicator for well-being, the result is in line with the argumentation that well-being is important for successful collaboration (Munkvold and Zigurs 2007).

Next to reflecting on our propositions, we see that in both virtual settings the values of each item decrease from the middle to the end of a VDT workshop. Based on the decline of four measures regarding SMM as well as the statement of both teams that VDT is more exhausting, we assume a negative effect on concentration that becomes apparent only in VDT but not in analog DT. In the given virtual setting, the team members had to use audio- and videoconferencing and digital whiteboards for (visual) communication at the same time and the participants' feedback indicates that higher time pressure, more exhaustion, and technical problems as well as leg-times negatively influenced the levels of SMM to the end of a collaboration. According to that, we reason that our artifact and the technical equipment (cable headphones and only one screen) needs to be improved also toward the involvement of team members who are less IT savvy (Lojeski et al. 2007).

Moreover, we refer to the occurrence of the McGurk Effect, even though not explicit, during the VDT workshop, because of disruptions in communication processes which led to challenges in terms of cognitive load. Cognitive load, in this case, can be identified through the decrease of shared representation (SMM) as well as a perceived higher exhaustion after the virtual collaboration.

MRT applies to our artifact as it is rich in terms of appropriate communication channels, which led to overall high levels of SMM in general (Daft and Lengel 1986). Nonetheless, the decrease of SMM might as well be explained with equivocation of rich information, seen in the results of SMM. Furthermore, the richness of an artifact can only be considered as one quality aspect when designing a specific setting of virtual collaboration. Summarizing, we can state that the performance of the VDT approach is not per se challenged by the digitalization of the DT process (Lattemann et al. 2017) nor by the applied tools and methods (Potthoff et al. 2018) but by a combination of technical (Gräßler et al., 2017) and socio-cognitive aspects (Redlich, Dorawa et al. 2018).

10.8 Conclusion and Outlook

With this research, we applied a socio-cognitive view on virtual collaboration for corporate innovation development with Design Thinking (DT). We analyzed the inherent challenges with technology use for the specific case of Virtual Design Thinking (VDT) (Gibbs et al. 2016). This paper aimed at identifying the influences of the use of virtual communications tools on VDT. We assessed the effects by referring to the psychological construct of Shared Mental Models (SMM). Summarizing, we can reveal that a VDT approach leads to high levels of the SMM knowledge structure 'team task, team goal, and performance requirements' as well as 'perceived satisfaction'. Nonetheless, a closer examination of the results reveals that challenges occurred, which negatively influenced the performance of VDT workshops in comparison to analog workshops, e.g. in terms of participants' exhaustion over time. Additionally, we identified a decrease of satisfaction and other SMM measures over the course of VDT and we identified the McGurk Effect caused by the settings in our experiments. Further, identified effects are supported by the MRT.

Hence, the complex collaboration mode – as illustrated in the beginning of this contribution – requires a rich artifact and a setting/concept as well as technical equipment that support ambitious cognitive processes like in VDT. A major implication that can be drawn from the results of this corporate experiment is that the level of technological advancement of our artifact is comparably low with an audio- and video-system and digital whiteboards. Nonetheless, the application of the comparably easy-to-use artifact was challenging for participants and fundamental infrastructure – stable internet connection, a second screen or wireless headsets – was missing. Therefore, a fast implementation of VDT to support distributed, shared, and corporate innovation processes requires an easy-to-use and user-friendly system. However, at this moment, we are skeptical toward the application of more advanced technological approaches such as the application of VR or AuR for VDT.

Summarizing, we can derive that CMC tools exist, which adequately support virtual innovation process, in particular a VDT workshop. These rich collaboration tools should likewise be easy-to-use. Hence, more advanced functionalities are not leading necessarily to better team performances in virtual collaboration. We also can state that the technological equipment in the medium-sized companies and the IT savviness of their employees still lack behind latest developments, although the study was performed in highly developed German cities.

Hence, for practitioners we can state that rich and adequately designed collaborations tools are necessary but not sufficient. To perform a successful VDT workshop, up-to-date equipment and skilled knowledge worker (in terms of IT and in terms of the innovation process) are needed. We assume that this also holds true for other formats of creative and agile workshops.

We can adhere that a socio-cognitive perspective toward VDT is necessary for future research to comply with the complex collaboration mode of DT. We suggest that more experiments with DT and VDT should be conducted, which also compare and analyze the performance as well as the outcome. This would enrich the solution space on how to improve the specific setting of virtual collaboration in the case of innovation development with DT. Also, the socio-cognitive evaluation presented in this paper, can be applied in other creative CMC processes to offer a human-centered perspective that considers the influence of factors such as exhaustion through media usage, stress through time restrictions, and overall team performance.

Furthermore, we suggest to expand the set of theories to explain socio-cognitive challenges of virtual collaboration such as the Media Synchronicity Theory or Social Load Theory to better understand how we can improve virtual creative collaboration like in DT.

10.9 Acknowledgements

This study is part of the project 'DETHIS – Design Thinking for Industrial Services', funded by the Federal Ministry of Education and Research (BMBF) of Germany, Grant 02K14A140.

11. General Conclusion

Design Thinking (DT) is an increasingly promoted innovation approach in the business world. But noticeable, an overload regarding DT in the corporate public can be recognized (brand eins 2019), which makes it even more important to scientifically examine DT to overcome the mystique, superficial, and the inflationary use of only the term. This dissertation revealed how the DT approach can be performed virtually and, thereby, introduced the application of a suitable, contemporary approach for innovation development for dispersed, globalized businesses, hence, referring to a VDT approach.

This contribution started with an introduction (chapter 1) where the need to establish a VDT approach was outlined from a practical as well as a scientific point of view. Furthermore, it was demonstrated that the research undertaking toward VDT is located at the intersection of IM, IS, and DS. The structure of the dissertation and an outline of the single research papers, that were conducted to pursue this cumulative dissertation, were presented.

Chapter 2 of this dissertation focused on the theoretical background within three subsections that outlined the relation of IS, DS, and IM to DT. In section 2.1, the field of IS was put in the context of DT by outlining an understanding of the field and IS research regarding a VDT approach. In this section, the role of IT artifacts, the four developments (globalization, service society, organizational transformation, and digitalization) that motivate IS research and the VDT approach were introduced. Further, the focus of this work was portrayed in order to examine VDT from a process-and performance-perspective, highlighting the socio-cognitive view this dissertation takes. Since DT is inherently based on creative teamwork, the aim to establish a complete VDT approach was grounded by a review on research on virtual creative teamwork, followed by the state of the art on research regarding virtually performed DT.

To understand the interconnections between IS, DS, and further IM, section 2.2 presented the evolution of DT as an innovation development approach. Here, the different understandings of artifacts, design, designerly thinking, and DT were discussed and demarcated for the benefit of the context of this work. This section ended with the portrayal of DT as an innovation development approach, which was then further put in the context of the term ‘innovation’, a depiction on IM, as well as a presentation of varying innovation development approaches to localize DT in current IM debates (section 2.3).

The theoretical background established the basis for the state of the art of DT (chapter 3). Based on past research, the three equivalent elements of DT, namely the DT process, the DT methods, and the DT mindset, were presented in detail. Furthermore, the aim to create a VDT approach necessitates to outline the basic principles of DT – collaboration, co-creation, creativity, and visualization – which complements the understanding toward the innovation development approach.

The theoretical background as well as the state of the art on commonly analog-performed DT inform the present research gap, which shows that past approaches toward virtualizing DT either focus on a technology-view or on specific parts of performing DT virtually (for example DT methods), which motivates the facilitation to develop a complete VDT approach from a socio-cognitive perspective in order to support corporate innovation processes. The underlying research questions of this dissertation were presented in chapter 4 and are referred to in the subsequent figure 25. To approach the research gap and respond to the research questions, chapter 5 introduced the overarching research methodology ADR as well as the dissertation-specific procedure. As part of the ADR procedure, five research papers (chapters 6-10) were developed that partly respond to the subsequent research questions. To create an overview, figure 25 illustrates the ways each research paper responded to certain aspects of the research questions. Moreover, all five research papers share the common goal of developing a VDT approach. The question how a VDT approach can be applied or be improved with regard to the DT process, methods, and mindset as well as the basic principles is shown on the left part of the figure 25. The right part of the figure refers to the question how the effectiveness of a VDT approach can be measured with regard to the three equivalent elements and the basic principles underlying DT from a socio-cognitive perspective. The numbers refer to the research papers and how each paper refers to certain aspects of the research questions.

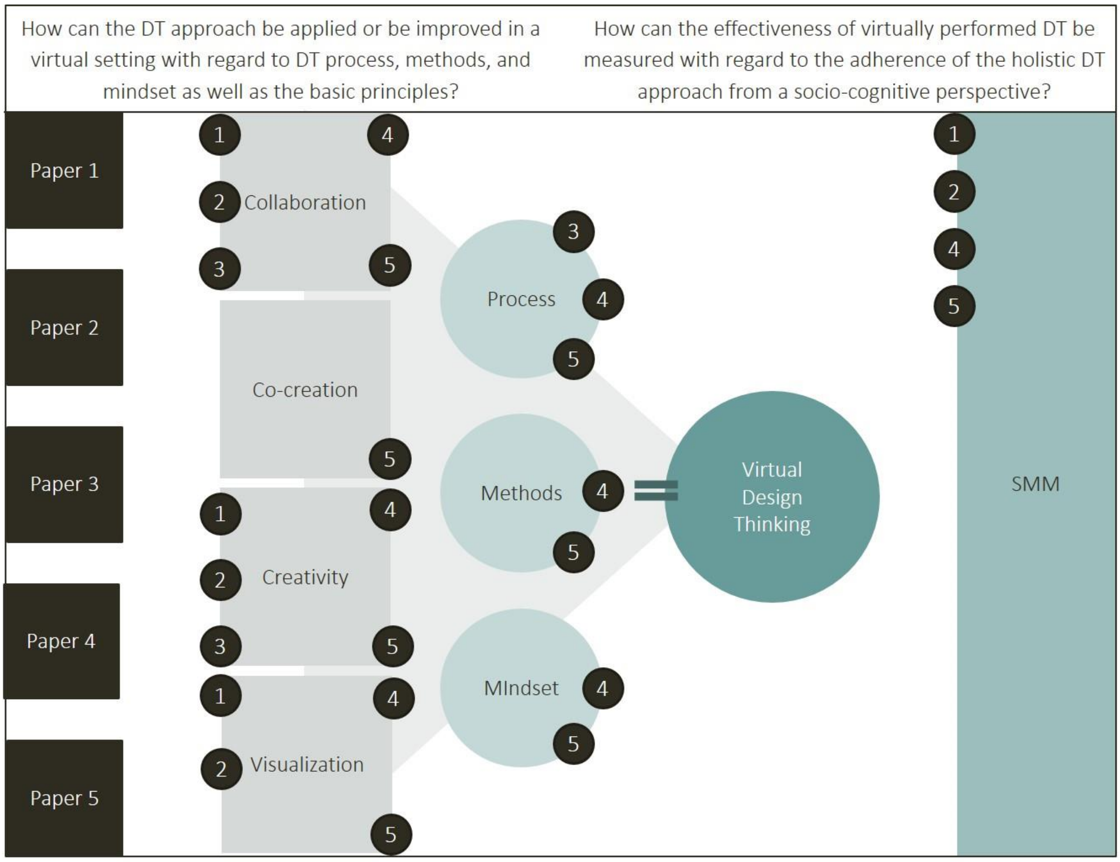

Figure 25 Overview of research questions and responses through single research papers

The performance of the ADR procedure together with the insights of the research papers reveal that DT can be performed virtually by the use of ICT tools and, thereby, adheres to the DT process, methods, mindset as well as the basic principles. Paper 3 'Digitization of the Design Thinking Process – Solving Problems with Geographically Dispersed Teams' shows that a combination of given ICT tools allow for the performance of the DT process while adhering to collaborative, co-creative, and creative setting that facilitates joint visualization. Summarizing, all five papers 1-5 reveal that, from an ICT perspective, the VDT approach can be performed by an artifact that consists of a digital whiteboard and an audio- and videoconference system to facilitate the basic principles in a dispersed, virtual setting. The artifact responds to the competencies and needs of users that vary in their level of IT competencies from high to low and it only requires a standard technical infrastructure (hardware and software). From a content perspective, the adherence of the holistic DT approach is only possible through the organization, conceptualization, and strong moderation of a trained DT coach. Whereas the artifact allows for a virtual setting in which the

VDT approach can be performed, the DT coach needs to conceptualize and moderate the DT workshops in compliance with the DT process, methods, and mindset. The combination of ICT tools with a DT coach as facilitator of the VDT approach represent the ensemble artifact that jointly approaches a co-creative and creative collaboration that is supported by visualization in teams for the purpose of corporate innovation development.

Moreover, paper 4 'Towards Semi-Virtual Design Thinking – Creativity in Dispersed Multicultural and Multidisciplinary Innovation Project Teams' shows that the VDT approach can additionally be performed in a hybrid manner of analog and virtually performed phases. This shows that the VDT approach can be applied flexibly and a switch from on-site and virtual settings supports the communication modes of DT teams.

Furthermore, the effectiveness of VDT was approached in papers 1-5. The focus of the process and performance of VDT motivated this research to apply a socio-cognitive view on the evaluation with regard to effectiveness. Due to the process- and performance perspective as well as the inherent cognitive styles in DT, the psychological construct of SMM was identified and applied as evaluation approach. Paper 1, 2, 4, and 5 show that by SMM the perceived effectiveness, satisfaction, and performance requirements can be measured when examining VDT. Paper 2 and 4, in particular, outline the strong relation between perceived effectiveness and satisfaction, ultimately highlighting that the effectiveness of performing VDT is linked with a satisfying experience of corporate innovation development. Especially the insights gained from paper 5 reveal that a VDT performance is perceived as effective and satisfying, which underlines that the application of the ensemble artifact establishes a successful VDT approach. Nonetheless, a virtual performance of DT adhering to the three equivalent elements and the basic principles is perceived minimally less satisfying than analog-performed DT, which was reflected in the light of media theories (MNT, MST, and MRT) in research papers 1, 2, 4, and 5 as well as with regard to the McGurk Effect (paper 5).

Although this dissertation shows how a VDT approach can be performed effectively and satisfyingly, the virtual setting improves only certain aspects in comparison to analog-performed DT, which derive mainly from the use of a digital whiteboard. The use of a digital instead of an on-site whiteboard increases creative mechanisms with regard to collaborative visualization, ultimately making the documentation of the DT approach easier in a digital sphere.

To summarize, this dissertation provided the theoretical background, research studies, and insights toward an effective VDT approach that can be performed for corporate innovation development in dispersed settings. The VDT approach, united in an ensemble artifact, was developed by applying the research methodology ADR, which allowed for the development of an improved corporate setting, in particular referring to dispersed corporate innovation development. The context of the problem situation, which is inherent in ADR, led to a VDT approach that integrates the companies' and stakeholder needs to improve a given problem situation. Hence, the context informs the solution space of the ensemble artifact, which led to an easy-to-use IT artifact that facilitates the performance of the complex requirements while adhering to the holistic DT approach. Following, the technological perspective of the VDT approach is less innovative but, therefore, allows for a virtual setting that can actually be applied in a corporate settings on a constant basis.

11.1 Summary of the Results

This dissertation addresses the need for corporate teamwork to be performed location-independent due to increasingly dispersed settings of companies, their employees, and their stakeholders. This holds also true for corporate innovation development. DT is an innovation development approach that is commonly performed location-dependent with multidisciplinary teams consisting of a diverse group of internal and external stakeholders of a company. The increasing performance of DT in businesses refers to the approaches' ability to creatively develop user-centered innovations. However, the analog performance of DT requires the presence of multiple stakeholders in dedicated innovation labs. This leads to efforts for companies that stand in contradiction to the increasingly dispersed corporate settings. Furthermore, IM research has shown that co-creation between employees, customers, and other stakeholders is vital for the flow of internal and external knowledge streams that contribute to innovation development. DT represents a suitable innovation development approach, but, thus far, cannot be performed location-independent. As a result, this dissertation presents a VDT approach that enables the performance of DT in a dispersed setting. The VDT approach is an ensemble artifact, which consists of an ICT-tool component, the DT coach as instance of facilitating the DT approach, the DT teams that perform the approach, and the context of applying the innovation development undertaking. The VDT approach can refer to the complete virtual performance or a hybrid version, namely semi-virtual workshops.

The results of this dissertation can be summarized from a (1) technological-, (2) process- and performance perspective, as well as (3) an evaluation approach and (4) the applicability of the VDT approach.

From a (1) technological perspective, this dissertation shows that ICT tools, which adequately support virtually performed DT, already exist. The most important ICT tools needed to perform VDT are a digital whiteboard and an audio-videoconference system. Following, the hard- and software requirements of VDT are comparably low and characterized by an easy-access and a possible performance from any location. Following, the acquirements and dispersed provisioning of advanced technology, such as AuR and VR hard- and software, are redundant. Furthermore, the results of the research papers show that more advanced technologies are not necessarily suiting the IT competences of stakeholders in virtual collaboration. However, a richness of the applied ICT tools with suitable functionalities that support the DT team members' needs is important and were found in the applied tools.

The (2) process- and performance perspective of the VDT approach refers to the conceptualization and accomplishment of the DT workshops that need to be accompanied and moderated by a DT coach to lead and moderate the DT teams through the innovation development procedure. The examination of the DT elements (DT process, method, and mindset) as well as the basic principles shows that DT can be characterized as a complex collaboration mode that also needs to be approached when performing VDT. Following, the VDT approach allows for an application of the thinking styles, reasoning modes, and cognitive processes in the collaborative setting. While synchronous CMC with an audio- and videoconference system is indispensable, so is virtual collaborative visualization. This dissertation outlines the positive effect of visualization in VDT. From a process- and performance perspective, this dissertation reveals that a combination of virtual and on-site DT workshops can be performed, which raises the flexibility of performing collaborative innovation development.

While concentrating on the performance of VDT, the identification of a suitable (3) evaluation approach to measure the effectiveness of the proposed approach is necessary. In accordance with the process- and performance perspective as well as the inherent cognitive demands inherent to DT, a socio-cognitive view on the evaluation of the VDT approach was set. The psychological construct of SMM, referring to a shared understanding that supports virtual creative teamwork, was found to serve the evaluation of the performance of VDT. As a result of this work, SMM can be considered to measure the perceived effectiveness and satisfaction when performing VDT as an indicator of success. Furthermore, MNT, MRT, MST, and the McGurk Effect were identified as means of comparison to the results of SMM in the context of applying the VDT artifact. Summarizing, the overall performance of VDT is successful referring to a high perceived effectiveness and satisfaction. However, the results of this research show that there is still space for improvement toward supporting cognitive processes in VDT. Although adhering to the holistic DT approach, the performance of VDT is not perceived as satisfactory as analog workshops and in completely virtual performed workshops an effect of exhaustion that negatively contributes to cognitive processes was found.

Since the performance of several VDT workshops with companies shows that the approach was generally perceived as successful, this dissertation contributes by (4) an actual applicability of the VDT approach. The ICT component of the VDT approach can be easily provided in a dispersed corporate setting, which raises the possibilities of an actual application of VDT. Although the VDT approach did not outperform the performance of analog DT, it reduces the efforts of location-dependence, adheres to the three equivalent elements of DT, and supports collaborative, co-creative, and creative innovation development by joint visualization in corporate settings, which was supported by the results of five research papers. As an alternative to analog DT, VDT, as a satisfactory and more flexible approach for corporate, user-centered innovation development, allows for an easier co-creation process.

11.2 Limitations and Implications for Research and Practice

This dissertation inherits limitations that will subsequently be outlined by nine major aspects and reflected vis-à-vis with the implications. First, a socio-cognitive view on VDT that inherits a process- and performance perspective neglects an output-perspective toward innovations. Although an effective and satisfying performance indicates a successful VDT approach, it does not reflect on the innovations that were developed. Ultimately, the impact of newly developed innovations on a company's success has not been examined, but it is recommended to identify and apply an evaluation approach from a VDT output-perspective for future research. Future research might consider to reflect VDT in the light of current debates on innovations, such as products, product-service-systems, services (e.g. digital- and personal services), business models, or processes, and furthermore, could be examined with regard to major developments, such as servitization and service-dominant-logic.

Second, this work excludes the fields of Management Education as well as Organization and Management for the benefit of adhering to the socio-cognitive view on the performance of VDT itself. However, there are strong connections of this work with Organization and Management due to the collaboration style of (V)DT that might impact an organization, its stakeholders, as well as its processes. The examination of performing VDT on an organizational level was outside the scope of this work, but an examination of organizational changes through VDT is strongly recommended for future research. Possible future research could, for example, focus on the role of mindsets through the application of VDT or how a company's co-creation is impacted by a lasting performance of VDT.

Third, a change from analog to virtual collaboration for specific corporate tasks cannot only be reasoned by increased technological opportunities, companies and their employees need to be motivated in changing their work routines and learning new working modes takes time, which needs to be respected and supported by a companies' leadership.

Fourth, this dissertation examined the establishment of a VDT approach in a corporate context, following a next step would be the investigation whether and how VDT can be implemented in a variety of companies, where different corporate settings would be of interest. For this dissertation, the VDT approach was performed with two companies, students, and associate partners. However, future studies could take different companies with different levels of employees' IT competences into account to further examine the relation of IT competencies regarding the performance of VDT. This might lead to an approach how more advanced technology (AuR and VR) can overcome the challenge of its actual application in daily business.

Fifth, the presented VDT approach leaves room for improvement, not only in further supporting cognitive processes, but also to reduce the efforts for DT coaches. Current studies that examine the facilitation of virtual moderation by artificial intelligence could be advanced toward a VDT focus by adhering to the holistic DT approach, which is a specific case of moderation.

Sixth, the easy-access IT artifact to perform VDT allows for a flexible use and low barrier to facilitate VDT, but future research and practice might also consider the development of a fully integrated software solution that allows for all communication modes and functionalities in one system. Additionally, past research on the virtual performance of DT methods need to be integrated in the system to examine whether this improves the VDT experience over the on-site DT approach.

Seventh, another major topic that can be identified in research on VDT is time independence. The presented VDT approach mainly considers location-independence, but a globalized business context can additionally be challenged by the aspect of time- and location-dependence at the same time with regard to global time differences, which affect the possibility for synchronous collaboration.

Eighth, with the conviction that VDT needs to be performed effectively and satisfactory to result in successful outputs, future research on creative virtual teamwork is encouraged to apply a socio-cognitive view. Although the human-centered perspective was applied for the VDT approach, it did not outperform analog DT. This especially supports the process- and performance perspective of this dissertation by applying a socio-cognitive view, because even the focus on perceived satisfaction and effectiveness did not lead to the overall improvement of VDT in comparison to analog DT. Hence, it is recommended that the digitalization of creative innovation approaches focuses on the human needs and the context to comply with a corporate applicability and with satisfactory development processes in a globalized business world.

Ninth, this dissertation does not claim of presenting the only possible socio-cognitive-inspired evaluation approach for VDT. Other constructs for the evaluation of VDT are possible, for example different constructs, theories, and effects that might support the generation of insights regarding VDT might be applicable, such as the Social Load Theory.

Ultimately, the developed VDT approach can be regarded as a step toward contemporary innovation development in dispersed settings, reflecting the necessities of IM in a globalized and digitalized business world. The virtual performance does not only save monetary resources, such as travel expenses, but might simplify the facilitation of co-creation and collaboration to support internal and external knowledge streams, which, in the light of open innovation, supports innovation development. Once more, the relevance to perform IS research for the benefit of improving corporate tasks that include the human, the IT, and the organization is underlined by the outcome of this dissertation.

11.3 Outlook and Final Remarks

The path toward and the established VDT approach of this dissertation does not only present how DT can be performed effectively and satisfyingly in a virtual setting. It additionally promotes an emphasis to examine, introduce, and implement virtual creative teamwork approaches that focus on the satisfaction of the user in order to support well-being and pleasure in performing corporate tasks in a globalized world. This dissertation shall endorse that not only an output is a valuable corporate measure, but also the path toward it is an important object of research. In the realm of VDT, an interdisciplinary examination from an IS, IM, and DS perspective was chosen, which allowed for an in-depth examination of DT.

By disclosing the roots and the state of the art on DT, the role and the importance of the innovation development approach for IM was outlined and a foundation was created how IS research allows for the establishment of a VDT approach. It is common to digitalize specific corporate tasks and processes, and hopefully suitable approaches for innovation development other than DT will be subject of future research on digitalization from a socio-cognitive view to improve corporate work in a globalized world for the benefit of its performers.

Science, companies, and employees are encouraged to examine, introduce, and test varying approaches of virtual collaboration, which might be new to people and take time to learn. But in the long-run, virtual collaboration for specific corporate processes becomes increasingly central to an effective performance of tasks, which needs to be reflected in science and practice at the right time.

Hopefully, this dissertation motivates science and practice to access, support, and promote creativity in collaborative, co-creative, and dispersed settings for the benefit of innovative progress and normalizing virtual creative teamwork that is based on a positive experience.

12. References

Abowd GD, Mynatt ED (2000) Charting Past, Present, and Future Research in Ubiquitous Computing. *ACM Transactions on Computer-Human Interaction* 7(1):29–58.

Almefelt L, Sutinen K, Malmqvist J (2003) Computer Support for Systematic Design Applied in a Cross-functional Commercial Concept Development Project. *Concurrent Engineering* 11(2):107–120.

Alrushiedat N, Olfman L (2012) Anchored Asynchronous Online Discussions: Facilitating Participation and Engagement in a Blended Environment. *Proceedings of 45th Hawaii International Conference on System Science (HICSS)*. 11–20.

Alter S (2015) The concept of "IT artifact" has outlived its usefulness and should be retired now. *Information Systems Journal* 25(1):47–60.

Amabile TM (1988) A Model of Creativity and Innovation in Organizations. *Research in Organizational Behavior* 22:123–167.

Amabile TM, Conti R, Coon H, Lazenby J, Herron M (1996) Assessing the Work Environment for Creativity. *The Academy of Management Journal* 39(5):1154–1184.

Appleton JV (1995) Analysing qualitative interview data: addressing issues of validity and reliability. *Journal of Advanced Nursing* 22(5):993–997.

Asana (2017) Asana. *Asana*. Retrieved (June 5, 2019), https://asana.com/de.

Badke-Schaub P, Roozenburg N, Cardoso C (2010) Design Thinking: A paradigm on its way from dilution to meaninglessness? *Proceedings of the 8th Design Thinking Research Symposium*:39–49.

Bailey DE, Kurland NB (2002) A review of telework research: findings, new directions, and lessons for the study of modern work. *Journal of Organizational Behavior* 23(4):383–400.

Bandura A (1986) Social Foundations of Thoughts and Actions. Marks DF, ed. *The Health Psychology Reader*. (SAGE), 94–106.

Banks AP, Millward LJ (2000) Running shared mental models as a distributed cognitive process. *British Journal of Psychology* 91(4):513–531.

Bartelt VL, Dennis AR (2014) Nature and Nurture: The Impact of Automaticity and the Structuration of Communication on Virtual Team Behavior and Performance. *MIS Quarterly* 38(2):521–538.

Baskerville R, Nandhakumar J (2007) Activating and Perpetuating Virtual Teams: Now That We're Mobile, Where Do We Go? *IEEE Transactions on Professional Communication* 50(1):17–34.

Batarseh FS, Usher JM, Daspit JJ (2016) Collaboration capability in virtual teams: examining the influence on diversity and innovation. *Int. J. Innov. Mgt.* 21(04):1–29.

Bauer RM, Eagan WM (2008) Design Thinking - Epistemic Plurality in Management and Organization. *Aesthesis* 2(3):64–74.

Baxter P, Jack S (2008) Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. *The Qualitative Report* 13(4):544–559.

Becker F, Siemon D, Meyer M (2019) Taking Action: Extending Participatory Action Design Research with Design Thinking. *Proceedings of 32nd Bled eConference*. (Slovenia), 1–9.

Bellet PS, Maloney MJ (1991) The Importance of Empathy as an Interviewing Skill in Medicine. *JAMA* 266(13):1831–1832.

Berge ZL (1999) Interaction in Post-Secondary Web-Based Learning. *EDUCATIONAL TECHNOLOGY* (39):5–11.

Bergiel BJ, Bergiel EB, Balsmeier PW (2008) Nature of virtual teams: a summary of their advantages and disadvantages. *Management Research News* 31(2):99–110.

Berthod O, Helfen M, Sydow J (2018) Institutional Work for Value Co-Creation: Navigating amid Power and Persistence. Vargo SL, Lusch RF, eds. *The SAGE Handbook of Service-Dominant Logic*. (SAGE), 800.

Beyhl T, Berg G, Giese H (2014) Connecting Designing and Engineering Activities. Leifer L, Plattner H, Meinel C, eds. *Design Thinking Research: Building Innovation Eco-Systems*. Understanding Innovation. (Springer International Publishing, Cham), 153–182.

Bittner EAC, Leimeister JM (2014) Creating Shared Understanding in Heterogeneous Work Groups: Why It Matters and How to Achieve It. *Journal of Management Information Systems* 31(1):111–144.

Blaser AD, Sester M, Egenhofer MJ (2000a) Visualization in an early stage of the problem-solving process in GIS. *Computers & Geosciences* 26(1):57–66.

Bogers M, Chesbrough H, Moedas C (2018) Open Innovation: Research, Practices, and Policies. *California Management Review* 60(2):5–16.

Boland RJ, Collopy F (2004) *Managing as Designing* 1st ed. (Stanford University Press, Stanford).

van den Bossche P, Gijselaers W, Segers M, Woltjer G, Kirschner P (2010) Team learning: building shared mental models. *Instr Sci* 39(3):283–301.

Both T (2009) The Bootcamp Bootleg. Retrieved (June 20, 2019) https://dschool.stanford.edu/resources/the-bootcamp-bootleg.

brand eins (2019) Die meistgehassten Buzzwords* DESIGN THINKING. *Pikstagram*. Retrieved (April 2, 2019), https://pikstagram.com/media/BvhHo7fJZlR.

Brenner W, Uebernickel F, Abrell T (2016) Design Thinking as Mindset, Process, and Toolbox. Brenner W, Uebernickel F, eds. *Design Thinking for Innovation*. (Springer International Publishing), 3–21.

Brereton M, McGarry B (2000) An Observational Study of How Objects Support Engineering Design Thinking and Communication: Implications for the design of tangible media. *CHI Letters* 2(1):217–224.

Bresciani S (2019) Visual Design Thinking: A Collaborative Dimensions framework to profile visualisations. *Design Studies* 63:92–124.

Breuer G, Eisele P (2018) *Design: Texte zur Geschichte und Theorie* (Reclam, Philipp, jun. GmbH, Verlag, Ditzingen).

Briggs RO, Vreede GJD, Nunamaker JF (2003) Collaboration Engineering with ThinkLets to Pursue Sustained Success with Group Support Systems. *Journal of Management Information Systems* 19(4):31–64.

Brown T (2008) Design Thinking. *Harvard Business Review* 86(6):84–92.

Brown T (2009) *Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation* (Harper Collins).

Buchanan R (1992) Wicked Problems in Design Thinking. *Design Issues* 8(2):5–21.

Bürdek BE (2015) *Design: Geschichte, Theorie und Praxis der Produktgestaltung* (Birkhäuser).

Burke CS, Stagl KC, Salas E, Pierce L, Kendall D (2006) Understanding team adaptation: a conceptual analysis and model. *J Appl Psychol* 91(6):1189–1207.

Butler ES, Aasheim C, Williams S (2007) Does telecommuting improve productivity? *Communications of the ACM* 50(4):101–103.

Cannon-Bowers JA, Salas E (2001) Reflections on shared cognition. *J. Organiz. Behav.* 22(2):195–202.

Cannon-Bowers JA, Salas E, Converse S (1993) Shared mental models in expert team decision making. Castellan NJ, ed. *Individual and Group Decision Making: Current Issues*. (Lawrence Erlbaum Associates, London), 221–246.

Carlgren L, Elmquist M, Rauth I (2014) Design Thinking: Exploring Values and Effects from an Innovation Capability Perspective. *The Design Journal* 17(3):403–423.

Carlgren L, Elmqvist M, Rauth I (2016) Exploring the use of design thinking in large organizations: Towards a research agenda. *Swedish Design Research Journal* 11(1):55–63.

Carlgren L, Rauth I, Elmquist M (2016) Framing Design Thinking: The Concept in Idea and Enactment. *Creativity and Innovation Management* 25(1):38–57.

Cherry E, Latulipe C (2014) Quantifying the Creativity Support of Digital Tools through the Creativity Support Index. *ACM Transactions on Computer-Human Interaction* 21(4):1–25.

Chesbrough HW (2006) *Open Innovation: The New Imperative for Creating and Profiting from Technology* (Harvard Business Press, Boston, MA).

Clutton-Brock A (2008) *William Morris* N.-A. (Parkstone International, New York).

Coates N, Ind N (2013) The meanings of co-creation. *European Business Review* 25(1):86–95.

Cooper RG (1990) Stage-gate systems: A new tool for managing new products. *Business Horizons* 33(3):44–54.

Corvera Charaf M, Rosenkranz C, Holten R (2013) The emergence of shared understanding: applying functional pragmatics to study the requirements development process. *Information Systems Journal* 23(2):115–135.

Costa AC (2003) Work team trust and effectiveness. *Personnel Review* 32(5):605–622.

Cronbach LJ (1951) Coefficient alpha and the internal structure of tests. *Psychometrika* 16(3):297–334.

Cronin JJ, Taylor SA (1992) Measuring Service Quality: A Reexamination and Extension. *Journal of Marketing* 56(3):55–68.

Cross N (1982) Designerly ways of knowing. *Design Studies* 3(4):221–227.

Cross N (1999) Design Research: A Disciplined Conversation. *Design Issues* 15(2):5–10.

Cross N (2001) Designerly Ways of Knowing: Design Discipline Versus Design Science. *Design Issues* 17(3):49–55.

Cross N (2011) *Design Thinking: Understanding How Designers Think and Work* (Berg).

Curtis AM, Dennis AR, McNamara KO (2017) From Monologue to Dialogue: Performative Objects to Promote Collective Mindfulness in Computer-Mediated Team Discussions. *MIS Quarterly* 41(2):559–581.

Daft RL, Lengel RH (1986) Organizational Information Requirements, Media Richness and Structural Design. *Management Science* 32(5):554–571.

Daniels K, Lamond D, Standen P (2001) Teleworking: Frameworks for Organizational Research. *Journal of Management Studies* 38(8):1151–1185.

Davis BM (2010) Creativity & Innovation in Business 2010 Teaching the Application of Design Thinking to Business. *Procedia - Social and Behavioral Sciences* 2(4):6532–6538.

Davison G, Blackman D (2005) The role of mental models in innovative teams. *Euro Jrnl of Inn Mnagmnt* 8(4):409–423.

DeFillippi R, Grabher G, Jones C (2007) Introduction to paradoxes of creativity: managerial and organizational challenges in the cultural economy. *Journal of Organizational Behavior* 28(5):511–521.

Dekeyser S, Watson R (2008) *Extending Google Docs to Collaborate on Research Papers* (The University of Southern Queensland, Australia).

DeLone WH, McLean ER (1992) Information Systems Success: The Quest for the Dependent Variable. *Information Systems Research* 3(1):60–95.

Dennis AR, Fuller RM, Valacich JS (2008) Media, Tasks, and Communication Processes: A Theory of Media Synchronicity. *MIS Quarterly* 32(3):575–600.

Dennis AR, Valacich JS (1999) Rethinking media richness: towards a theory of media synchronicity. *Proceedings of the 32nd Annual Hawaii International Conference on Systems Sciences (HICSS)*. 1–10.

Dennis R, Valacich JS, Connolly T, Wynne BE (1996) Process Structuring in Electronic Brainstorming. *Information Systems Research* 7(2):268–277.

Design Council UK (2007) *The Design Process: What is the Double Diamond?*

DETHIS (2019) DETHIS Methoden. *Design Thinking für industrienahe Dienstleistungen*. Retrieved (February 21, 2019), https://designthinking-methoden.de/.

DIN - Deutsches Institut für Normung (2018) DIN - Deutsches Institut für Normung. *DIN Spec 33543 Entwicklung digitaler Dienstleistungssysteme*. Retrieved (July 3, 2019), https://www.din.de/de/wdc-beuth:din21:285703329.

DIN - Deutsches Institut für Normung e. V. (1998) *DIN-Fachbericht 75: Service Engineering_-Entwicklungsbegleitende Normung (EBN) für Dienstleistungen* (Beuth Verlag GmbH).

Doorley S, Holcomb S, Klebahn P, Segovia K, Utley J (2018) Design Thinking Bootleg. https://static1.squarespace.com/static/57c6b79629687fde090a0fdd/t/5b19b2f2aa4a99e99b26b6bb/1528410876119/dschool_bootleg_deck_2018_final_sm+%282%29.pdf.

Doorley S, Witthoft S (2011) *Make Space: How to Set the Stage for Creative Collaboration* 1st ed. Hasso Plattner Institute of Design at Stanford University, ed. (John Wiley & Sons, Hoboken, N.J).

Dörner D, Bick T (1983) *Lohhausen: vom Umgang mit Unbestimmtheit und Komplexität* (Huber).

Dorst K (2006) Design Problems and Design Paradoxes. *Design Issues* 22(3):4–17.

Dorst K (2011) The core of 'design thinking' and its application. *Design Studies* 32(6):521–532.

Dosi C, Rosati F, Vignoli M (2018) Measuring Design Thinking Mindset. *DS92 Proceedings of the DESIGN 2018*. 1991–2002.

Douglas PM, Isherwood B (2002) *The World of Goods* 1st ed. (Routledge, London).

Dropbox (2017) Dropbox. *Dropbox*. Retrieved (June 5, 2019), https://www.dropbox.com/.

Drucker PF (2002) The Discipline of Innovation. *Harvard Business Review* Best of HBR 1985:5–11.

d.school Paris (2019) our d.school process. *d.school Paris*. Retrieved (July 26, 2019), http://www.dschool.fr/design-thinking/.

d.school Stanford (2009) Steps in a Design Thinking Process. *Steps in a Design Thinking Process*. Retrieved (September 18, 2017), https://dschool-old.stanford.edu/groups/k12/wiki/17cff/steps_in_a_design_thinking_process.html.

Dunne D (2018) Implementing design thinking in organizations: an exploratory study. *Journal of Organization Design* 7(1):1–16.

Dunne D, Martin R (2006) Design Thinking and How It Will Change Management Education: An Interview and Discussion. *Academy of Management Learning & Education* 5(4):512–523.

Ebrahim NA (2015) Virtual R&D Teams: A New Model for Product Development. *International Journal of Innovation* 3(2):1–27.

Efeoğlu A, Møller C, Sérié M (2013) Solution Prototyping with Design Thinking – Social Media for SAP Store: A Case Study. *Design Science: Perspectives from Europe*. (Springer, Cham), 99–110.

Elsbach KD, Stigliani I (2018) Design Thinking and Organizational Culture: A Review and Framework for Future Research. *Journal of Management* 44(6):2274–2306.

Erlhoff M, Marshall T, Bruce L, Lindberg S (2007) *Design Dictionary: Perspectives on Design Terminology* (Walter de Gruyter GmbH, Basel/Berlin/Boston, SWITZERLAND).

Farrell TSC (2012) Reflecting on Reflective Practice: (Re)Visiting Dewey and Schön. *TESOL Journal* 3(1):7–16.

Fink A (2002) *How to Ask Survey Questions* (SAGE).

Fischer F, Bruhn J, Gräsel C, Mandl H (2002) Fostering collaborative knowledge construction with visualization tools. *Learning and Instruction* 12(2):213–232.

Fischer S, Redlich B, Gernreich C, Poeppelbuss J, Lattemann C (2019) Implementation of Design Thinking in an SME. *Proceedings of ISPIM 2019*. (Florenz), 1–14.

Florida R (2014) *The Rise of the Creative Class-Revisited* 2nd ed. (Basic Books, New York).

Friedman B, Kahn PH, Borning A (2008) Value Sensitive Design and Information Systems. Himma KE, Tavani HT, eds. *The Handbook of Information and Computer Ethics*. (John Wiley & Sons), 69–102.

Frow P, Nenonen S, Payne A, Storbacka K (2015) Managing Co-creation Design: A Strategic Approach to Innovation. *Brit J Manage* 26(3):463–483.

Funke J (2009) Complex problem solving: a case for complex cognition? *Cogn Process* 11(2):133–142.

Furmanek L, Daurer S (2019) Application of Media Synchronicity Theory to Creative Tasks in Virtual Teams Using the Example of Design Thinking. *Tagungsband WI 2019*. (Siegen), 1846–1857.

Gabriel A, Monticolo D, Camargo M, Bourgault M (2016) Creativity support systems: A systematic mapping study. *Thinking Skills and Creativity* 21:109–122.

Gabriel R (2016) Enzyklopaedie der Wirtschaftsinformatik. *Informationssystem*. Retrieved (June 21, 2019), http://www.enzyklopaedie-der-wirtschaftsinformatik.de/wi-enzyklopaedie/lexikon/uebergreifendes/Kontext-und-Grundlagen/Informationssystem/index.html.

Gallupe RB, Dennis AR, Cooper WH, Valacich JS, Bastianutti LM, Nunamaker JF (1992) Electronic Brainstorming And Group Size. *AMJ* 35(2):350–369.

Gericke L, Wenzel M, Meinel C (2014) Asynchronous understanding of creative sessions using archived collaboration artifacts. *2014 International Conference on Collaboration Technologies and Systems (CTS)*. 41–48.

Gibbons JD, Chakraborti S (2011) Nonparametric Statistical Inference. Lovric M, ed. *International Encyclopedia of Statistical Science*. (Springer Berlin Heidelberg), 977–979.

Gibbs JL, Sivunen A, Boyraz M (2016) Investigating the impacts of team type and design on virtual team processes. *Human Resource Management Review*:1–14.

Gibson CB, Gibbs JL (2006) Unpacking the Concept of Virtuality: The Effects of Geographic Dispersion, Electronic Dependence, Dynamic Structure, and National Diversity on Team Innovation. *Administrative Science Quarterly* 51(3):451–495.

Gilson LL, Maynard MT, Young NCJ, Vartiainen M, Hakonen M (2015) Virtual Teams Research 10 Years, 10 Themes, and 10 Opportunities. *Journal of Management* 41(5):1313–1337.

Goldkuhl G (2013) From ensemble view to ensemble artefact – An inquiry on conceptualisations of the IT artefact. *Systems, Signs & Actions* 7(1):49–72.

Goldschmidt G (2007) To see eye to eye: the role of visual representations in building shared mental models in design teams. *CoDesign* 3(1):43–50.

Goller I, Bessant J (2017) *Creativity for Innovation Management* (Routledge).

Goodwin K (2011) *Designing for the Digital Age: How to Create Human-Centered Products and Services* (John Wiley & Sons).

Google Docs (2017) Google Docs. *Google Docs*. Retrieved (June 5, 2019), https://www.google.com/intl/de_de/docs/about/.

Google Hangouts (2017) Google Hangouts. *Google Hangouts*. Retrieved (June 5, 2019), https://hangouts.google.com/webchat/start.

Gräßler I, Taplick P, Pottebaum J (2017) Enhancing innovation processes by disruptive technologies. 19–26.

Gregor S, Hevner AR (2013) Positioning and Presenting Design Science Research for Maximum Impact. *MIS Quarterly* 37(2):337-A6.

Grots A, Pratschke M (2009) Design Thinking — Kreativität als Methode. *Thexis* 26(2):18–23.

Gumienny R, Gericke L, Quasthoff M, Willems C, Meinel C (2011) Tele-Board: Enabling efficient collaboration in digital design spaces. *Proceedings of the 2011 15th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*. 47–54.

Gumienny R, Gericke L, Wenzel M, Meinel C (2013) Supporting creative collaboration in globally distributed companies. *Proceedings of the 2013 conference on Computer supported cooperative work - CSCW '13*. (ACM Press, San Antonio, Texas, USA), 995–1006.

Güther M, Hartmann L (2017) Spacedeck. *Spacedeck*. Retrieved (August 23, 2016), https://spacedeck.com/.

Guthrie JP (2001) High-Involvement Work Practices, Turnover, and Productivity: Evidence from New Zealand. *AMJ* 44(1):180–190.

Hargadon AB, Bechky BA (2006) When Collections of Creatives Become Creative Collectives: A Field Study of Problem Solving at Work. *Organization Science* 17(4):484–500.

Harker Martin B, MacDonnell R (2012) Is telework effective for organizations?: A meta-analysis of empirical research on perceptions of telework and organizational outcomes. *Management Research Review* 35(7):602–616.

Harpaz I (2002) Advantages and disadvantages of telecommuting for the individual, organization and society. *Work Study* 51(2):74–80.

Hartmann B, Morris MR, Benko H, Wilson AD (2010) Pictionaire: Supporting Collaborative Design Work by Integrating Physical and Digital Artifacts. *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work*. CSCW '10. (ACM, New York, NY, USA), 421–424.

Hassi L, Laakso M (2011) CONCEPTIONS OF DESIGN THINKING IN THE DESIGN AND MANAGEMENT DISCOURSES. :1-10.

Hehn J, Uebernickel F, Herterich M (2018) Design Thinking Methods for Service Innovation - A Delphi Study. :1–15.

Henderson A (2006) Review of "The Semantic Turn: A New Foundation for Design by Klaus Krippendorff." *Taylor & Francis* 13(6):56–59.

Hess T (2019) Digitalisierung — Enzyklopaedie der Wirtschaftsinformatik. *Digitalisierung*. Retrieved (June 29, 2019), http://www.enzyklopaedie-der-wirtschaftsinformatik.de/lexikon/technologien-methoden/Informatik--Grundlagen/digitalisierung/index.html/?searchterm=digitalisierung.

Hevner AR, March ST, Park J, Ram S (2004) Design Science in Information Systems Research. *MIS Quarterly* 28(1):75–105.

Hjørland B (2002) Epistemology and the socio-cognitive perspective in information science. *Journal of the American Society for Information Science and Technology* 53(4):257–270.

Hollan J, Hutchins E, Kirsh D (2000) Distributed Cognition: Toward a New Foundation for Human-computer Interaction Research. *ACM Transactions on Computer-Human Interaction* 7(2):174–196.

Howard Z, Senova M, Melles G (2015) Exploring the role of mindset in design thinking: Implications for capability development and practice. *Journal of Design, Business & Society* 1(2):183–202.

Howkins J (2013) *The Creative Economy: How People Make Money from Ideas* 2nd ed. (Penguin UK, UK).

HPI d.school (2018) Design Thinking-Prozess - Hintergrund - Design Thinking. *Die sechs Schritte im Design Thinking Innovationsprozess*. Retrieved (August 1, 2018), https://hpi.de/school-of-design-thinking/design-thinking/hintergrund/design-thinking-prozess.html.

IDEO.ORG (2018a) Create Insight Statements. *Design Kit*. Retrieved (June 14, 2017), http://www.designkit.org/methods/62.

IDEO.ORG (2018b) Define your Audience. *Design Kit*. Retrieved (June 14, 2017), http://www.designkit.org/methods/11.

IDEO.ORG (2018c) Gut Check. *Design Kit*. Retrieved (June 14, 2017), http://www.designkit.org/methods/42.

IDEO.ORG (2018d) Journey Map. *Design Kit*. Retrieved (June 14, 2017), http://www.designkit.org/methods/63.

IDEO.ORG (2019) Design Kit. *Design Kit*. Retrieved (September 16, 2016), http://www.designkit.org/methods#filter.

Iivari J, Venable JR (2009) Action research and design science research - Seemingly similar but decisively dissimilar. (AISEL), 1–13.

Järvinen P (2007) Action Research is Similar to Design Science. *Qual Quant* 41(1):37–54.

Jeong H, Chi MTH (2007) Knowledge convergence and collaborative learning. *Instr Sci* 35(4):287–315.

Johansson U, Woodilla J (2010) Bridging design and management for sustainability: Epistemological problems and possibilities. *Positive Design and Appreciative Construction: From Sustainable Development to Sustainable Value*. Advances in Appreciative Inquiry. (Emerald Group Publishing Limited), 57–75.

Johansson-Sköldberg U, Woodilla J, Çetinkaya M (2013) Design Thinking: Past, Present and Possible Futures. *Creativity and Innovation Management* 22(2):121–146.

Johnson S (2010) *Where Good Ideas Come From: The Natural History of Innovation* (Penguin UK).

Johnson TE, Lee Y, Lee M, O'Connor DL, Khalil MK, Huang X (2007) Measuring Sharedness of Team-Related Knowledge: Design and Validation of a Shared Mental Model Instrument. *Human Resource Development International* 10(4):437–454.

Ju W, Neeley L, Winograd T, Leifer L (2006) *Thinking with erasable ink: Ad-hoc whiteboard use in collaborative design* (Standford University, Standford).

Justinmind (2017) Justinmind. *Justinmind*. Retrieved (June 5, 2019), https://www.justinmind.com/.

Kanawattanachai P, Yoo Y (2007) The Impact of Knowledge Coordination on Virtual Team Performance over Time. *MIS Quarterly* 31(4):783–808.

Karpova E, Correia AP, Baran E (2009) Learn to use and use to learn: Technology in virtual collaboration experience. *The Internet and Higher Education* 12(1):45–52.

Kelley T, Littman J (2001) *The art of innovation: lessons in creativity from IDEO, America's leading design firm* 1st ed. (Currency/Doubleday, New York).

Kelley T, Littman J (2005) *The Ten Faces of Innovation* 1st ed. (Doubleday, New York).

Keppel G (1991) *Design and analysis: A researcher's handbook (3rd ed.)* (Prentice-Hall, Inc, Englewood Cliffs, NJ, US).

Keuper F, Hamidian K, Verwaayen E, Kalinowski T, Kraijo C (2013) *Digitalisierung und Innovation: Planung - Entstehung - Entwicklungsperspektiven* (Springer).

Kimbell L (2009) Beyond design thinking: Design-as-practice and designs-in-practice. *Proceedings of CRESC*. (Manchester), 1–15.

Kimbell L (2011) Rethinking Design Thinking: Part I. *Design and Culture* 3(3):285–306.

Kimbell L (2012) Rethinking Design Thinking: Part II. *Design and Culture* 4(2):129–148.

Kirkman BL, Mathieu JE (2005) The Dimensions and Antecedents of Team Virtuality. *Journal of Management* 31(5):700–718.

Kirschner F, Paas F, Kirschner PA (2009) A Cognitive Load Approach to Collaborative Learning: United Brains for Complex Tasks. *Educ Psychol Rev* 21(1):31–42.

Klimoski R, Mohammed S (1994) Team Mental Model: Construct or Metaphor? *Journal of Management* 20(2):403–437.

Kniberg H (2018) Web Whiteboard. *Web Whiteboard*. Retrieved (June 13, 2018), https://webwhiteboard.com/.

vam Knippenberg D, Schippers MC (2007) Work Group Diversity. *Annual Review of Psychology* 58(1):515–541.

Kock N (2004) The Psychobiological Model: Towards a New Theory of Computer-Mediated Communication Based on Darwinian Evolution. *Organization Science* 15(3):327–348.

Kolkman MJ, Kok M, van der Veen A (2005) Mental model mapping as a new tool to analyse the use of information in decision-making in integrated water management. *Physics and Chemistry of the Earth, Parts A/B/C* 30(4–5):317–332.

Kolko J (2010) Abductive Thinking and Sensemaking: The Drivers of Design Synthesis. *Design Issues* 26(1):15–28.

Kolko J (2015) Design Thinking Comes of Age. *Harvard Business Review* (September 2015) (September 1) https://hbr.org/2015/09/design-thinking-comes-of-age.

Kratzer J, Leenders OThAJ, Engelen JML van (2004) Stimulating the Potential: Creative Performance and Communication in Innovation Teams. *Creativity and Innovation Management* 13(1):63–71.

Krippendorff K (2005) *The Semantic Turn: A New Foundation for Design* (CRC Press, New York).

Kurian GT (2013) *The AMA Dictionary of Business and Management* (Amacom, New York).

Lande M, Sonalkar N, Jung M, Han C, Banerjee S (2012) Monitoring Design Thinking Through In-Situ Interventions. Plattner H, Meinel C, Leifer L, eds. *Design Thinking Research: Studying Co-Creation in Practice*. Understanding Innovation. (Springer Berlin Heidelberg, Berlin, Heidelberg), 211–226.

Landman RB, Broek EL van den, Gieskes JFB (2009) Creating Shared Mental Models: The Support of Visual Language. Luo Y, ed. *Cooperative Design, Visualization, and Engineering*. Lecture Notes in Computer Science. (Springer Berlin Heidelberg), 161–168.

Langan-Fox J, Anglim J, Wilson JR (2004) Mental models, team mental models, and performance: Process, development, and future directions. *Human Factors and Ergonomics in Manufacturing & Service Industries* 14(4):331–352.

Lattemann C, Fritz K (2014) Learning Integrative Thinking. *Proceedings of Society for Information Technology & Teacher Education International Conference*. 1857–1864.

Lattemann C, Robra-Bissantz S (2005) Customer Integration – Social and Technology Based Concepts for a Customer Governance. *FRONTIERS OF E-BUSINESS RESEARCH*:193–205.

Lattemann C, Robra-Bissantz S (2006) Customer governance : IC based concepts for a successful customer integration. Hannula M, Järvelin AM, Seppä M, eds. *Frontiers of e-Business Research*.

Lattemann C, Siemon D, Dorawa D, Redlich B (2017) Digitization of the design thinking process solving problems with geographically dispersed teams. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* 10288 LNCS:71–88.

Laudon KC, Laudon JP, Schoder D (2010) *Wirtschaftsinformatik: eine Einführung* (Pearson Deutschland GmbH).

Lawrence C, Tuunanen T, Myers MD (2010) Extending Design Science Research Methodology for a Multicultural World. *Human Benefit through the Diffusion of Information Systems Design Science Research*. (Springer Berlin Heidelberg), 108–121.

Lawson B (1980) *How Designers Think* 1. (Architectural Press).

Lawson B (2006) *How designers think: the design process demystified* 4. ed. (Elsevier/Architectural Press, Amsterdam).

Leavy B (2012) Collaborative innovation as the new imperative – design thinking, value co-creation and the power of "pull." *Strategy & Leadership* 40(2):25–34.

Liedtka J (2011) Learning to use design thinking tools for successful innovation. *Strategy & Leadership* 39(5):13–19.

Liedtka J, King A, Bennett K (2013) *Solving Problems with Design Thinking: Ten Stories of What Works* (Columbia University Press, New York).

Liedtka J, Ogilvie T (2011) *Designing for Growth: A Design Thinking Tool Kit for Managers* (Columbia University Press).

Lim BC, Klein KJ (2006) Team mental models and team performance: a field study of the effects of team mental model similarity and accuracy. *J. Organiz. Behav.* 27(4):403–418.

Lind MR, Zmud RW (1991) The Influence of a Convergence in Understanding Between Technology Providers and Users on Information Technology Innovativeness. *Organization Science* 2(2):195–217.

Lindberg T, Köppen E, Rauth I, Meinel C (2012) On the Perception, Adoption and Implementation of Design Thinking in the IT Industry. Plattner H, Meinel C, Leifer L, eds. *Design Thinking Research*. Understanding Innovation. (Springer Berlin Heidelberg), 229–240.

Link GJP, Siemon D, Vreede GJ de, Robra-Bissantz S (2015) Evaluating Anchored Discussion to Foster Creativity in Online Collaboration. Baloian N, Zorian Y, Taslakian P, Shoukouryan S, eds. *Collaboration and Technology*. Lecture Notes in Computer Science. (Springer International Publishing), 28–44.

Lipnack J, Stamps J (1999) Virtual teams: The new way to work. *Strategy & Leadership* 27(1):14–19.

Liu Z, Nersessian N, Stasko J (2008) Distributed Cognition as a Theoretical Framework for Information Visualization. *IEEE Transactions on Visualization and Computer Graphics* 14(6):1173–1180.

Liu Z, Stasko J (2010) Mental Models, Visual Reasoning and Interaction in Information Visualization: A Top-down Perspective. *IEEE Transactions on Visualization and Computer Graphics* 16(6):999–1008.

Lojeski KS, Reilly R, Dominick P (2007) Multitasking and Innovation in Virtual Teams. *Proceedings of 40th Annual Hawaii International Conference on System Sciences (HICSS)*. 1–9.

Lurey JS, Raisinghani MS (2001) An empirical study of best practices in virtual teams. *Information & Management* 38(8):523–544.

Lusch RF, Nambisan S (2015) Service Innovation: A Service-Dominant Logic Perspective. *MIS Quarterly* 39(1):155–175.

Mabrito M (2006) A Study of Synchronous Versus Asynchronous Collaboration in an Online Business Writing Class. *American Journal of Distance Education* 20(2):93–107.

Maccani G, Donnellan B, Helfert M (2015) Action design research: a comparison with canonical action research and design science. (DESRIST 2015), 1–8.

MacDonald J (2018) Hearing Lips and Seeing Voices: the Origins and Development of the 'McGurk Effect' and Reflections on Audio–Visual Speech Perception Over the Last 40 Years. *Multisensory Research* 31(1–2):7–18.

Martin R (2009) *The Design of Business: Why Design Thinking is the Next Competitive Advantage* 1st ed. (Harvard Business Press, Boston, MA).

Martinez-Moyano IJ (2006) Exploring the dynamics of collaboration in interorganizational settings. Schuman S, ed. *Creating a Culture of Collaboration: The International Association of Facilitators Handbook*. (John Wiley & Sons), 69–85.

Martins LL, Gilson LL, Maynard MT (2004) Virtual Teams: What Do We Know and Where Do We Go From Here? *Journal of Management* 30(6):805–835.

Martins LL, Shalley CE (2011) Creativity in Virtual Work: Effects of Demographic Differences. *Small Group Research* 42(5):536–561.

Marvel (2017) POP - Prototyping on Paper. *App Store - POP*. Retrieved (June 5, 2019), https://itunes.apple.com/de/app/pop-prototyping-on-paper/id555647796?mt=8.

Massetti B (1996) An Empirical Examination of the Value of Creativity Support Systems on Idea Generation. *MIS Quarterly* 20(1):83–97.

Mathieu J, Maynard MT, Rapp T, Gilson L (2008) Team Effectiveness 1997-2007: A Review of Recent Advancements and a Glimpse Into the Future. *Journal of Management* 34(3):410–476.

Mathieu JE, Heffner TS, Goodwin GF, Salas E, Cannon-Bowers JA (2000) The influence of shared mental models on team process and performance. *Journal of Applied Psychology* 85(2):273–283.

Maynard TM, Gilson LL (2014) The Role of Shared Mental Model Development in Understanding Virtual Team Effectiveness. *Group & Organization Management* 39(1):3–32.

McCraw TK (2007) *Prophet of innovation: Joseph Schumpeter and creative destruction* (Belknap Press of Harvard University Press, Cambridge, Mass).

McGurk H, MacDonald J (1976) Hearing lips and seeing voices. *Nature* 264(5588):746–748.

Meinel C, Leifer L (2012) Design Thinking Research. Plattner H, Meinel C, Leifer L, eds. *Design Thinking Research*. Understanding Innovation. (Springer Berlin Heidelberg), 1–10.

Merriam-Webster Inc (2003) *Merriam-Webster's collegiate dictionary.* 11th ed. (Merriam-Webster, Incorporated, Springfield, MA).

Milliken FJ, Bartel CA, Kurtzberg T (2003) Diversity and creativity in work groups: A dynamic perspective on the affective and cognitive processes that link diversity and performance. Paulus PB, Nijstad BA, eds. *Group Creativity: Innovation through Collaboration*. (Oxford University Press), 32–62.

Mohammed S, Klimoski R, Rentsch JR (2000) The Measurement of Team Mental Models: We Have No Shared Schema. *Organizational Research Methods* 3(2):123–165.

Moholy-Nagy L (1961) *Vision in motion.* (P. Theobald, Chicago).

Mullarkey MT, Hevner AR (2015) Entering Action Design Research. *New Horizons in Design Science: Broadening the Research Agenda*. (Springer, Cham), 121–134.

Müller RM, Thoring K (2012) Design thinking vs. lean startup: A comparison of two user-driven innovation strategies. *Proceedings of DMI*. 91–106.

Munkvold BE, Zigurs I (2007) Process and technology challenges in swift-starting virtual teams. *Information & Management* 44(3):287–299.

Myers KK, Sadaghiani K (2010) Millennials in the Workplace: A Communication Perspective on Millennials' Organizational Relationships and Performance. *J Bus Psychol* 25(2):225–238.

Mynatt ED, Igarashi T, Edwards WK, LaMarca A (1999) Flatland: New Dimensions in Office Whiteboards. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '99. (ACM, New York, NY, USA), 346–353.

Nunamaker JF, Briggs RO (2015) Introduction to Collaboration Systems and Technology Track. *Proceedings of the 48th Hawaii International Conference on System Sciences (HICSS)*. HICSS '15. (IEEE Computer Society, Washington, DC, USA), 1.

Nunamaker JF, Minder C, Purdin TDM (1990) Systems Development in Information Systems Research. *Journal of Management Information Systems* 7(3):89–106.

van Oorschot JAWH, Hofman E, Halman JIM (2018) A bibliometric review of the innovation adoption literature. *Technological Forecasting and Social Change* 134:1–21.

Orlikowski W, Robey D (1991) Information Technology and the Structuring of Organizations. *Information Systems Research* 2(2):143–169.

Orlikowski WJ, Iacono CS (2001) Research Commentary: Desperately Seeking the "IT" in IT Research—A Call to Theorizing the IT Artifact. *Information Systems Research* 12(2):121–134.

Oxman R (2017) Thinking difference: Theories and models of parametric design thinking. *Design Studies* 52:4–39.

Pawlowski JM (2013) Globalisierung — Enzyklopaedie der Wirtschaftsinformatik. *Globalisierung*. Retrieved (June 29, 2019), http://www.enzyklopaedie-der-wirtschaftsinformatik.de/lexikon/uebergreifendes/Globalisierung/index.html/?searchterm=Globalisierung.

Peffers K, Tuunanen T, Rothenberger MA, Chatterjee S (2007) A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems* 24(3):45–77.

Petersson AM, Lundberg J (2016) Applying Action Design Research (ADR) to Develop Concept Generation and Selection Methods. *Procedia CIRP* 50:222–227.

Petrykowski M, Berger P, Hennig P, Meinel C (2019) Digital Collaboration with a Whiteboard in Virtual Reality. Arai K, Bhatia R, Kapoor S, eds. *Proceedings of the Future Technologies Conference (FTC) 2018*. Advances in Intelligent Systems and Computing. (Springer International Publishing), 962–981.

Pevsner N (2005) *Pioneers of Modern Design: From William Morris to Walter Gropius* (Yale University Press, Yale).

Plattner H, Meinel C, Leifer L (2010) *Design Thinking: Understand – Improve – Apply* (Springer Science & Business Media).

van der Pol J, Admiraal W, Simons PRJ (2006) The affordance of anchored discussion for the collaborative processing of academic texts. *Computer Supported Learning* 1(3):339–357.

Potthoff T, Siemon D, Wilms K, Möser S, Hellmann M, Stieglitz S, Robra-Bissantz S (2018) Collaborative Service Blueprinting for Design Thinking: Evaluation of a Digital Prototype. *Proceedings of the 51st Hawaii International Conference on System Sciences (HICSS)*. 4584–4593.

Prahalad CK, Ramaswamy V (2000) Co-opting Customer Competence. *Harvard Business Review*(January–February 2000) (January 1) https://hbr.org/2000/01/co-opting-customer-competence.

Prahalad CK, Ramaswamy V (2004) Co-creation experiences: The next practice in value creation. *Journal of Interactive Marketing* 18(3):5–14.

Prud'homme van Reine P (2017) The culture of design thinking for innovation. *Journal of Innovation Management* 5(2):56–80.

Purao S, Henfridsson O, Rossi M, Sein M (2013) Ensemble artifacts : from viewing to designing in action design research. *Systems, Signs & Actions* 7(1):73–81.

Raffaele C, Connell J (2016) Telecommuting and Co-Working Communities: What Are the Implications for Individual and Organizational Flexibility? Sushil, Connell J, Burgess J, eds. *Flexible Work Organizations: The Challenges of Capacity Building in Asia*. Flexible Systems Management. (Springer India, New Delhi), 21–35.

Raghuram S, Tuertscher P, Garud R (2009) Research Note—Mapping the Field of Virtual Work: A Cocitation Analysis. *Information Systems Research* 21(4):983–999.

Randrup N, Druckenmiller D, Briggs RO (2016) Philosophy of Collaboration. *Proceedings of 49th Hawaii International Conference on System Sciences (HICSS)*. 898–907.

Rao VP (2018) EFFECTIVE REMOTE DESIGN THINKING: A BASIC ESSENTIAL FOR GLOBAL COMPANIES TO DEVELOP INNOVATIVE SOLUTIONS. *International Research Journal of Marketing and Economics* 5(7):1–15.

Rauth I, Köppen E, Jobst B, Meinel C (2010) Design Thinking: An Educational Model towards Creative Confidence. *DS 66-2: Proceedings of the 1st International Conference on Design Creativity (ICDC)*. 1–8.

Reckwitz A (2012) *Die Erfindung der Kreativität: zum Prozess gesellschaftlicher Ästhetisierung* (Suhrkamp).

Redlich B, Becker F, Fischer S, Fromm J, Gernreich C, Lattemann C, Pöppelbuß J, Siemon D, Wilms K (2019 - forthcoming) Das DETHIS-Verfahren - Design Thinking für das Service Engineering in kleinen und mittelständischen Unternehmen. *Digitale Dienstleistungsinnovation*. (Springer).

Redlich B, Becker F, Siemon D, Robra-Bissantz S, Lattemann C (2018) Nutzerzentrierte Dienstleistungsinnovation durch digitales Design Thinking – Herausforderung und Potenziale für Wissenschaft und Praxis. *Service Business Development*. (Springer Gabler, Wiesbaden), 83–102.

Redlich B, Dorawa D, Siemon D, Lattemann C (2018) Towards Semi-Virtual Design Thinking - Creativity in Dispersed Multicultural and Multidisciplinary Innovation Project Teams. *Proceedings of the 51st Hawaii International Conference on System Sciences (HICSS)*. 717–726.

Redlich B, Rechtien C, Schaub N (2019) Auf das Mindset kommt es an! Design Thinking für industrienahe Dienstleistungen analog oder digital. *HMD* 56(1):121–134.

Redlich B, Siemon D, Lattemann C, Robra-Bissantz S (2017) Shared Mental Models in Creative Virtual Teamwork. *Proceedings of the 50th Hawaii International Conference on System Sciences (HICSS)*. 464–473.

Rentsch JR, Klimoski RJ (2001) Why do 'great minds' think alike?: antecedents of team member schema agreement. *Journal of Organizational Behavior* 22(2):107–120.

Resick CJ, Murase T, Bedwell WL, Sanz E, Jiménez M, DeChurch LA (2010) Mental model metrics and team adaptability: A multi-facet multi-method examination. *Group Dynamics: Theory, Research, and Practice* 14(4):332–349.

Rhodes M (1961) An Analysis of Creativity. *The Phi Delta Kappan* 42(7):305–310.

Rittel HWJ, Webber MM (1973) Dilemmas in a general theory of planning. *Policy Sci* 4(2):155–169.

Rive P, Karmoker S (2016) Design Thinking Methods and Creative Technologies in Virtual Worlds. *Academic Conference International Limited*. 635–644.

Robra-Bissantz S, Siemon D (2019) Kooperationen in der Digitalen Wirtschaft. *HMD Praxis der Wirtschaftsinformatik*. Digitale Zusammenarbeit. (Springer, Wiesbaden), 7–21.

Roßbach M (2009) Creative Innovation – Insights from Neurobiology and Economics and Their Implications for Social Decision-Making. Jansen SA, Schröter E, Stehr N, eds. *Rationalität der Kreativität? Multidisziplinäre Beiträge zur Analyse der Produktion, Organisation und Bildung von Kreativität*. (VS Verlag für Sozialwissenschaften, Wiesbaden), 13–29.

Rothwell R (1994) Towards the Fifth-generation Innovation Process. *International Marketing Review* 11(1):7–31.

Rouse WB, Cannon-Bowers JA, Salas E (1992) The role of mental models in team performance in complex systems. *IEEE Transactions on Systems, Man, and Cybernetics* 22(6):1296–1308.

Rouse WB, Morris NM (1986) On looking into the black box: Prospects and limits in the search for mental models. *Psychological Bulletin* 100(3):349–363.

Rowe PG (1987) *Design Thinking* (MIT Press).

Salas E, Burke CS, Cannon-Bowers JA (2000) Teamwork: emerging principles. *International Journal of Management Reviews* 2(4):339–356.

Sandmann P (2000) *Telearbeit-Impulse für eine zukunftsfähige Regionalentwicklung?: Fallbeispiele aus dem Silicon Valley und Los Angeles für" Lernende Regionen"*. (Ruhr-Universität Bochum, Bochum).

Santos CM, Uitdewilligen S, Passos AM (2015) Why is Your Team More Creative Than Mine? The Influence of Shared Mental Models on Intra-group Conflict, Team Creativity and Effectiveness. *Creativity and Innovation Management* 24(4):645–658.

Schmiedgen J, Rhinow H, Köppen E (2016) *Parts without a whole?: The current state of Design Thinking practice in organizations* 1st ed. (Universitätsverlag Potsdam, Potsdam).

Schoberth T, Schrott G (2001) Virtual Communities. *Wirtschaftsinf* 43(5):517–519.

Schön DA (1983) *The reflective practitioner: how professionals think in action* 1st ed. (Ashgate Publishing, Abindon).

Schouten AP, Hooff B van den, Feldberg F (2016) Virtual Team Work Group Decision Making in 3D Virtual Environments. *Communication Research* 43(2):180–210.

Schuh G, Bender D (2012) Grundlagen des Innovationsmanagements. *Innovationsmanagement*. (Springer Berlin Heidelberg), 1–16.

Schumpeter JA (1934) *The Theory of Economic Development: An Inquiry Ito Profits, Capital, Credit, Interest, and the Business Cycle* 1st ed. (Harvard University Press, Cambridge, Mass).

Schweitzer J, Groeger L, Sobel L (2016) The Design Thinking Mindset: An Assessment of What We Know and What We See in Practice. *Journal of Design, Business & Society* 2(1):71–94.

Seidel VP, Fixson SK (2013) Adopting Design Thinking in Novice Multidisciplinary Teams: The Application and Limits of Design Methods and Reflexive Practices. *J Prod Innov Manag* 30:19–33.

Sein MK, Henfridsson O, Purao S, Rossi M, Lindgren R (2011) Action Design Research. *MIS Quarterly* 35(1):37–56.

Shalley CE (1995) Effects of Coaction, Expected Evaluation, and Goal Setting on Creativity and Productivity. *The Academy of Management Journal* 38(2):483–503.

Shneiderman B (2007) Creativity Support Tools: Accelerating Discovery and Innovation. *Communication ACM* 50(12):20–32.

Shu Q, Tu Q, Wang K (2011) The Impact of Computer Self-Efficacy and Technology Dependence on Computer-Related Technostress: A Social Cognitive Theory Perspective. *International Journal of Human-Computer Interaction* 27(10):923–939.

Siemon D (2019) *IT-Supported Collaborative Creativity*. (TU Braunschweig, Braunschweig).

Siemon D, Becker F, Robra-Bissantz S (2018) How Might We? From Design Challenges to Business Innovation. *Journal of Creativity and Business Innovation* (4):96–110.

Siemon D, Redlich B, Lattemann C, Robra-Bissantz S (2017) Forming Virtual Teams – Visualization with Digital Whiteboards to Increase Shared Understanding, Satisfaction and Perceived Effectiveness. *ICIS 2017 Proceedings*:1–17.

Siemon D, Robra-Bissantz S (2014) Integration of Information Retrieval in Creativity Support: A Prototype to Support Divergent Thinking. Tremblay MC, VanderMeer D, Rothenberger M, Gupta A, Yoon V, eds. *Advancing the Impact of Design Science: Moving from Theory to Practice*. Lecture Notes in Computer Science. (Springer Cham), 388–392.

Sievers C, Schröder N (2001) *50 Klassiker, Design des 20. Jahrhunderts* (Gerstenberg, Hildesheim).

Simon HA (1969) *The Sciences of the Artificial* 1st ed. (MIT Press, Masachusetts).

Skype (2017) Skype. *Skype*. Retrieved (June 5, 2019), https://www.skype.com/de//.

Slack (2017) Slack: Be less busy. *Slack*. Retrieved (August 23, 2016), https://slack.com/.

Smith JB, Barclay DW (1997) The Effects of Organizational Differences and Trust on the Effectiveness of Selling Partner Relationships. *Journal of Marketing* 61(1):3–21.

Sonnenburg S (2007) *Kooperative Kreativität: Theoretische Basisentwürfe und Organisationale Erfolgsfaktoren* (Deutscher Universitäts Verlag, Wiesbaden).

Soo Meng JC (2009) Donald Schön, Herbert Simon and The Sciences of the Artificial. *Design Studies* 30(1):60–68.

Sorapure M (2010) Information Visualization, Web 2.0, and the Teaching of Writing. *Computers and Composition* 27(1):59–70.

Spence JW, Tsai RJ (1997) On human cognition and the design of information systems. *Information & Management* 32(2):65–73.

Staples DS, Wong I, Seddon PB (2002) Having expectations of information systems benefits that match received benefits: does it really matter? *Information & Management* 40(2):115–131.

Steiner ID (1972) *Group Processes and Productivity* 2nd ed. (Academic Press).

Stickdorn M, Schneider J (2012) *This is Service Design Thinking: Basics, Tools, Cases* 3rd ed. Stickdorn M, Schneider J, eds. (BIS Publ.).

Suarez-Battan M (2012) Mural. *Mural*. Retrieved (August 23, 2016), https://mural.co/.

Swaab RI, Dumay ACM, Postmes T, Neijens P, Kiers MH (2002) Multiparty Negotiation Support: The Role of Visualization's Influence on the Development of Shared Mental Models. *Journal of Management Information Systems* 19(1):129–150.

Taggar S (2002) Individual Creativity and Group Ability to Utilize Individual Creative Resources: A Multilevel Model. *The Academy of Management Journal* 45(2):315–330.

Tan FB, Hunter MG (2002) The Repertory Grid Technique: A Method for the Study of Cognition in Information Systems. *MIS Quarterly* 26(1):39–57.

Tang A, Lanir J, Greenberg S, Fels S (2009) Supporting Transitions in Work: Informing Large Display Application Design by Understanding Whiteboard Use. *Proceedings of the International Conference on Supporting Group Work*. GROUP '09. (ACM, New York, NY, USA), 149–158.

Taura T, Yamamoto E, Fasiha MYN, Goka M, Mukai F, Nagai Y, Nakashima H (2012) Constructive simulation of creative concept generation process in design: a research method for difficult-to-observe design-thinking processes. *Journal of Engineering Design* 23(4):297–321.

Tavakol M, Dennick R (2011) Making sense of Cronbach's alpha. *Int J Med Educ* 2:53–55.

Thomas DM, Bostrom RP (2007) The Role of a Shared Mental Model of Collaboration Technology in Facilitating Knowledge Work in Virtual Teams. *Proceedings of 40th Annual Hawaii International Conference on System Sciences (HICSS)*. 37–37.

Thoring K, Müller RM (2011) Understanding Design Thinking: A Process Model based on Method Engineering. Kovacevic A, Ion W, McMahon C, Lyndon B, Hogarth P, eds. *DS 69: Proceedings of E&PDE 2011*. (London), 493–498.

Townsend AM, DeMarie SM, Hendrickson AR (1998) Virtual teams: Technology and the workplace of the future. *AMP* 12(3):17–29.

Tschimmel K (2012) Design Thinking as an effective Toolkit for Innovation. *ISPIM Conference Proceedings*. (Barcelona), 1–20.

Tuckman BW (1965) Developmental Sequence in Small Groups. *Psychological Bulletin* 63(6):384–399.

Tuckman BW, Jensen MAC (1977) Stages of Small-Group Development Revisited. *Group & Organization Management* 2(4):419–427.

Tushman M, Nadler D (1986) Organizing for Innovation. *California Management Review* 28(3):74–92.

Unger D, Witte EH (2007) Virtuelle Teams — Geringe Kosten, geringer Nutzen? Zur Leistungsverbesserung von Kleingruppen beim Problemlösen durch elektronische Moderation. *Gruppendynamik* 38(2):165–182.

Valacich JS, Dennis AR, Nunamaker JF (1992) Group Size and Anonymity Effects on Computer-Mediated Idea Generation. *Small Group Research* 23(1):49–73.

Vargo SL, Lusch RF (2017) Service-dominant logic 2025. *International Journal of Research in Marketing* 34(1):46–67.

Veling L, Quillan LM, Browne A, Craig M, Pinkster M (2016) Use It or Lose It: Embodying Practice in Action Design Research (ADR). *ICIS 2016 Proceedings*:1–16.

Veling L, Thornley C, Murnane S, Browne A, McQuillan L (2015) Selecting a Suitable Methodology for Designing Innovative Solutions to Support Capability Improvement in a Complex Organisational Context as part of an Industry- Academic Collaboration. *Proceedings of 18th Annual Irish Academy of Management Conference*. 1–21.

Verband der Hochschullehrer für Betriebswirtschaft e.V. (2019) Verband der Hochschullehrer für Betriebswirtschaft e.V.: Ziele. *Ziele*. Retrieved (February 13, 2019), http://tie.vhbonline.org/ziele/.

Verganti R (2009) *Design-driven Innovation: Changing the Rules of Competition by Radically Innovating what Things Mean* (Harvard Business Press).

Vilhelmson B, Thulin E (2016) Who and where are the flexible workers? Exploring the current diffusion of telework in Sweden. *New Technology, Work and Employment* 31(1):77–96.

Voigt M, Bergener K (2013) Enhancing Creativity in Groups – Proposition of an Integrated Framework for Designing Group Creativity Support Systems. *Proceedings of 46th Hawaii International Conference on System Sciences (HICSS)*. 225–234.

de Vreede G, Briggs RO (2005) Collaboration Engineering: Designing Repeatable Processes for High-Value Collaborative Tasks. *Proceedings of the 38th Annual Hawaii International Conference on System Sciences (HICSS)*. 1–10.

de Vreede T, Boughzala I, Vreede GJ de, Reiter-Palmon R (2012) A Model and Exploratory Field Study on Team Creativity. *Proceedings of the 45th Hawaii International Conference on System Science (HICSS)*. 227–236.

Waks LJ (2001) Donald Schon's Philosophy of Design and Design Education. *International Journal of Technology and Design Education* 11(1):37–51.

Walls JG, Widmeyer GR, El Sawy OA (1992) Building an Information System Design Theory for Vigilant EIS. *Information Systems Research* 3(1):36–59.

Walny J, Carpendale S, Riche NH, Venolia G, Fawcett P (2011) Visual Thinking In Action: Visualizations As Used On Whiteboards. 1-10.

Ware C (2012) *Information Visualization: Perception for Design* 3rd ed. (Elsevier, Waltham, MA).

Warkentin ME, Sayeed L, Hightower R (1997) Virtual Teams versus Face-to-Face Teams: An Exploratory Study of a Web-based Conference System*. *Decision Sciences* 28(4):975–996.

Webster J, Wong WKP (2008) Comparing traditional and virtual group forms: identity, communication and trust in naturally occurring project teams. *International Journal of Human Resource Management* 19(1):41–62.

Weekley E (2013) *An Etymological Dictionary of Modern English* 1st ed. (Dover Publications).

Weick KE, Roberts KH (1993) Collective Mind in Organizations: Heedful Interrelating on Flight Decks. *Administrative Science Quarterly* 38(3):357.

Wenzel M, Gericke L, Gumienny R, Meinel C (2013) Towards cross-platform collaboration - Transferring real-time groupware to the browser. *Proceedings of the 2013 IEEE 17th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*. 49–54.

Wenzel M, Gericke L, Gumienny R, Meinel C (2014) Creative Collaboration in Real World Settings. Leifer L, Plattner H, Meinel C, eds. *Design Thinking Research: Building Innovation Eco-Systems*. Understanding Innovation. (Springer International Publishing, Cham), 115–134.

Wenzel M, Gericke L, Thiele C, Meinel C (2016) Globalized Design Thinking: Bridging the Gap Between Analog and Digital for Browser-Based Remote Collaboration. *Design Thinking Research*. Understanding Innovation. (Springer, Cham), 15–33.

Whitworth B, Gallupe B, Mcqueen R (2000) A Cognitive Three-Process Model of Computer-Mediated Group Interaction. *Group Decision and Negotiation* 9:431–456.

de Winter JCF, Dodou D (2010) Five-Point Likert Items: t test versus Mann-Whitney-Wilcoxon. *Practical Assessment, Research & Evaluation* 15(11):1–12.

Wood R, Ashfield J (2008) The use of the interactive whiteboard for creative teaching and learning in literacy and mathematics: a case study. *British Journal of Educational Technology* 39(1):84–96.

Woodman RW, Sawyer JE, Griffin RW (1993) Toward a Theory of Organizational Creativity. *ACAD MANAGE REV* 18(2):293–321.

WorkingOn (2017) WorkingOn. *WorkingOn*. Retrieved (June 5, 2019), https://www.workingon.co.

Wylant B (2008) Design Thinking and the Experience of Innovation. *Design Issues* 24(2):3–14.

Yoo Y (2013) The Tables Have Turned: How Can the Information Systems Field Contribute to Technology and Innovation Management Research? *Journal of the Association for Information Systems* 14(5):227–236.

Yusoff NM, Salim SS (2015) A systematic review of shared visualisation to achieve common ground. *Journal of Visual Languages & Computing* 28:83–99.

zendesk (2017) InVision | Digital product design, workflow & collaboration. *InVision*. Retrieved (June 5, 2019), https://www.invisionapp.com/.

Zhang D, Lowry PB, Lina Zhou, Xiaolan Fu (2007) The Impact of Individualism--Collectivism, Social Presence, and Group Diversity on Group Decision Making Under Majority Influence. *Journal of Management Information Systems* 23(4):53–80.

13. Appendix

Paper 2 - Appendix: Survey:

Shared understanding of team task and goals (Johnson et al., 2007; Santos et al., 2015)	M^{EG}	SD^{EG}	M^{CG}	SD^{CG}
My team does what they are assigned to do.	1.70	0.80	3.75	0.77
My team has a shared goal for various project tasks.	1.80	0.77	3.65	0.75
My team discusses its goal and attains the agreement of teammates.	1.90	0.64	3.60	0.68
My team knows the general process involved in conducting a given task.	2.10	0.64	3.80	0.83
My team communicates with other teammates while performing team tasks.	1.95	0.76	3.95	0.76
My team uses a common vocabulary in task discussions.	1.70	0.92	2.80	0.62
My team shares information and individual team members do not keep information to themselves.	1.90	0.91	3.30	0.80
My team is committed to the team goal.	1.95	0.83	3.75	0.79
Everybody in my team strives to express his or her opinion.	2.25	0.79	4.40	0.75
My team understands their roles and responsibilities for doing various team tasks.	2.10	0.79	3.80	0.95
My team understands where they can get information for doing various team tasks.	1.75	0.91	3.85	0.75
My team informs each other about different work issues.	2.10	0.97	3.05	0.83
My team is likely to make a decision together.	1.65	0.67	4.00	0.86
My team understands how they can exchange information for doing various team tasks.	1.85	0.67	4.55	0.51
My team solves problems that occur while doing various team tasks.	1.80	0.77	3.75	1.12
There is an atmosphere of trust in my team.	2.00	0.97	2.75	0.72
My team creates a work environment that promotes productive results.	2.05	1.00	3.15	0.88
My team creates a safe environment to openly discuss any issue related to the team's success.	1.80	0.83	2.65	0.67
My team often utilizes different opinions for the sake of obtaining optimal outcomes.	2.35	1.04	3.20	0.95
My team has a positive team climate.	1.80	0.77	2.65	0.59
My team has the right experience so that a critical mass of experienced people is available on the team.	1.80	0.89	4.10	0.72
Satisfaction (Dennis et al., 1996, Santos et al., 2015)	M^{EG}	SD^{EG}	M^{CG}	SD^{CG}
How satisfied are you with the functioning of your team?	2.10	0.64	3.35	0.88

How satisfied are you with the results?	2.20	1.15	3.40	0.99
How satisfied are you with the communication among your team members?	2.25	1.12	3.35	0.93
How satisfied are you with the decisions made by your team?	1.95	0.69	4.20	0.89
How satisfied are you with the participation in your team?	1.95	1.05	3.35	0.88
How satisfied are you with your teamwork?	1.95	0.89	3.40	0.99
How satisfied are you with your team?	1.95	0.83	3.00	0.92
Perceived effectiveness (Dennis et al., 1996)	M^{EG}	SD^{EG}	M^{CG}	SD^{CG}
How effective was your team working on the problem?	2.10	0.55	3.70	0.85
How effective was your group at using all members' skills?	2.50	0.76	3.55	1.16
How effective was your team in structuring the problem or the task?	2.10	0.72	3.85	1.23
How effective was this meeting versus previous face-to-face meetings**	3.45	0.76	4.00	0.67
Structured interaction (Alrushiedat and Olfman, 2012; van der Pol et al., 2006)	M^{EG}	SD^{EG}	M^{CG}	SD^{CG}
The group discussion was structured.	2.10	0.64	4.40	0.50
The group spent little time discussing their procedure.	2.10	0.72	3.95	0.83
The discussion was focused on the assigned task.	1.55	0.76	3.35	0.67
Group members explained often what they mean.*	2.40	0.68	2.25	0.55
The discussion was task oriented and not personal or criticizing.**	1.45	0.61	1.80	0.70
**inverted*				
***considered independently*				

14. Acknowledgements

This work would not have been possible without all the people that supported me throughout the years in different ways. First and foremost, I want to thank my PhD-supervisor Christoph for the trust in me, the support, and the amazing collaboration. This effort requires high appreciation, which I like to express with these lines. My gratitude further extends to my dissertation committee, Olivier and Susn, for providing me with your support. I enjoyed the vivid discussions and your efforts to guide me toward pursuing my PhD.

Furthermore, I would like to thank my colleagues and friends from Jacobs University Ricardo, Simon, David, Lily, Raoul, Regina, Mandi, and Victor for constantly accompanying me, collaborating with me, listening to my worries, and reinforcing me. This also holds true for my colleagues from Braunschweig, where my special thanks goes to Dominik who was a true mentor for me from the first second of the PhD onwards, as well as to Felix, Rangina, and the whole work group who shared their thoughts and visions with me, which was a great matter of inspiration. Being part of a strong research and practice community has innumerable advantages and, hence, all partners of the DETHIS-project, especially our company partner, deserve a special thanks from my side for the great collaboration.

I truly believe that pursuing my PhD would have been impossible without the lasting support of my family and friends in all its recurring periods of joy and concerns. Unlike me, my parents and sisters never questioned that this path is the right one for me. Thank you for steadily backing me – this is unimaginable valuable. The same holds true for my friends, who all know that family and friendship are my source of happiness and energy. Without all of you being part of my life, I couldn’t enjoy a single second of it. The level of support you gave me cannot ever be taken for granted. Thank you Annika, Tobi, Katja, Jana, Marieke, Johanna, Irina, Svenja, Marlene, Kathrin, Sarah, and Pina.

The whole experiences within the last years will influence my future unchangeably and there were even more uncountable conversations and discussions that positively influenced this path, and to all of these people I express my gratitude.